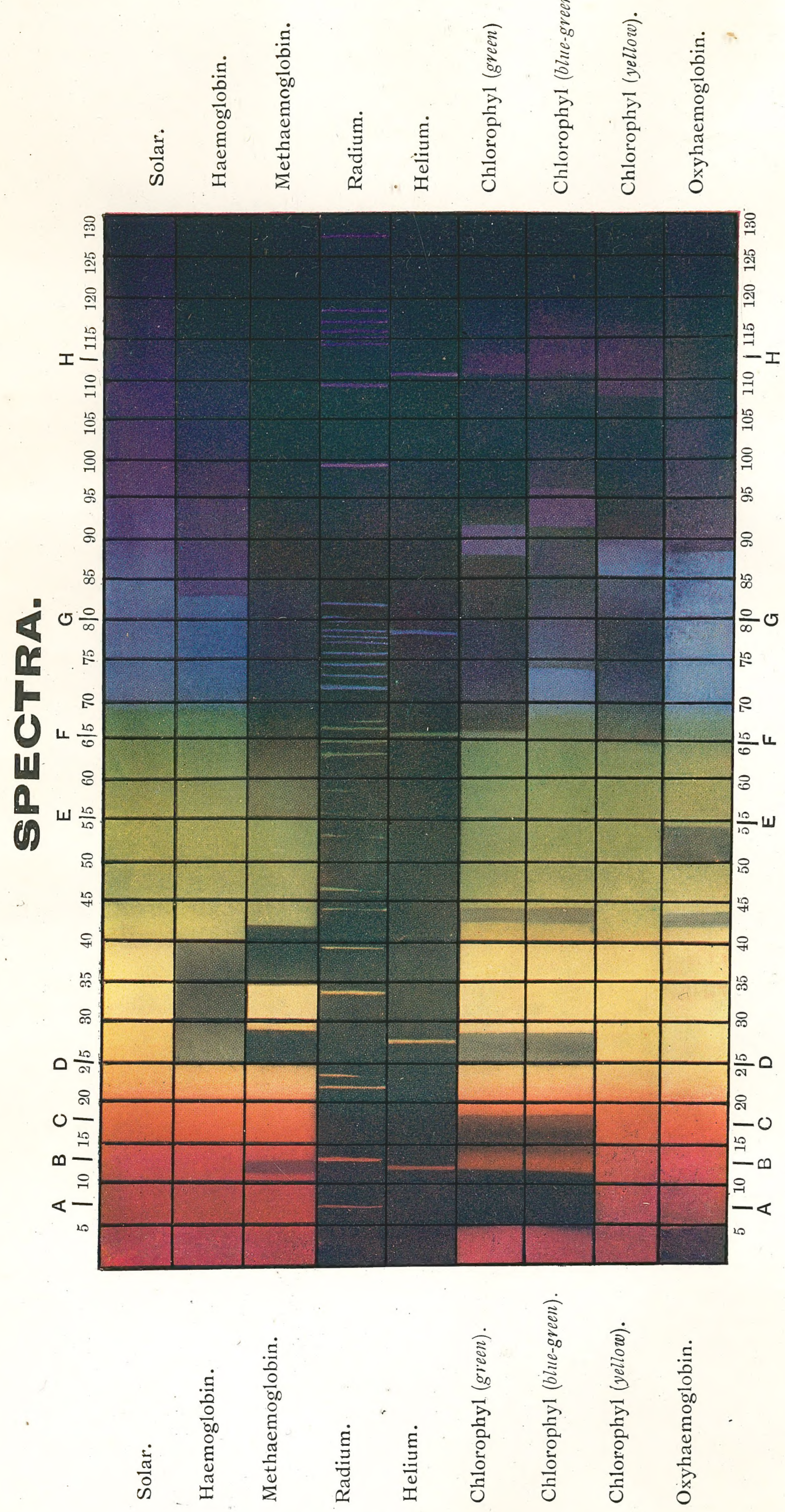
LIGHT
ENERGY

CLEAVES



Frontispiece to "Light Energy" by M. A. CLEAVES, M.D. (New York).

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LIGHT ENERGY

Its Physics, Physiological Action and Therapeutic Applications

By

MARGARET A. CLEAVES, M.D.

[illegible] of the New York Academy of Medicine; Fellow of the [illegible] Therapeutic Association; Member of the New [illegible] Medical Society; Fellow of the Société Française [illegible]; Fellow of the American Electro-[illegible] Society; Member of the Society of American [illegible]; Member of the New York Electrical Society; Professor of Light Energy in the New York School of Physical Therapeutics; Late Instructor in Electro-Therapeutics in the New York Post-Graduate Medical School

[illegible] ILLUSTRATIONS IN THE TEXT AND A FRONTISPIECE IN COLORS

"[illegible] light and sight be separate and independent [illegible] then if you remove light and darkness, there is [illegible] space."—*Buddhistic Sutra.*

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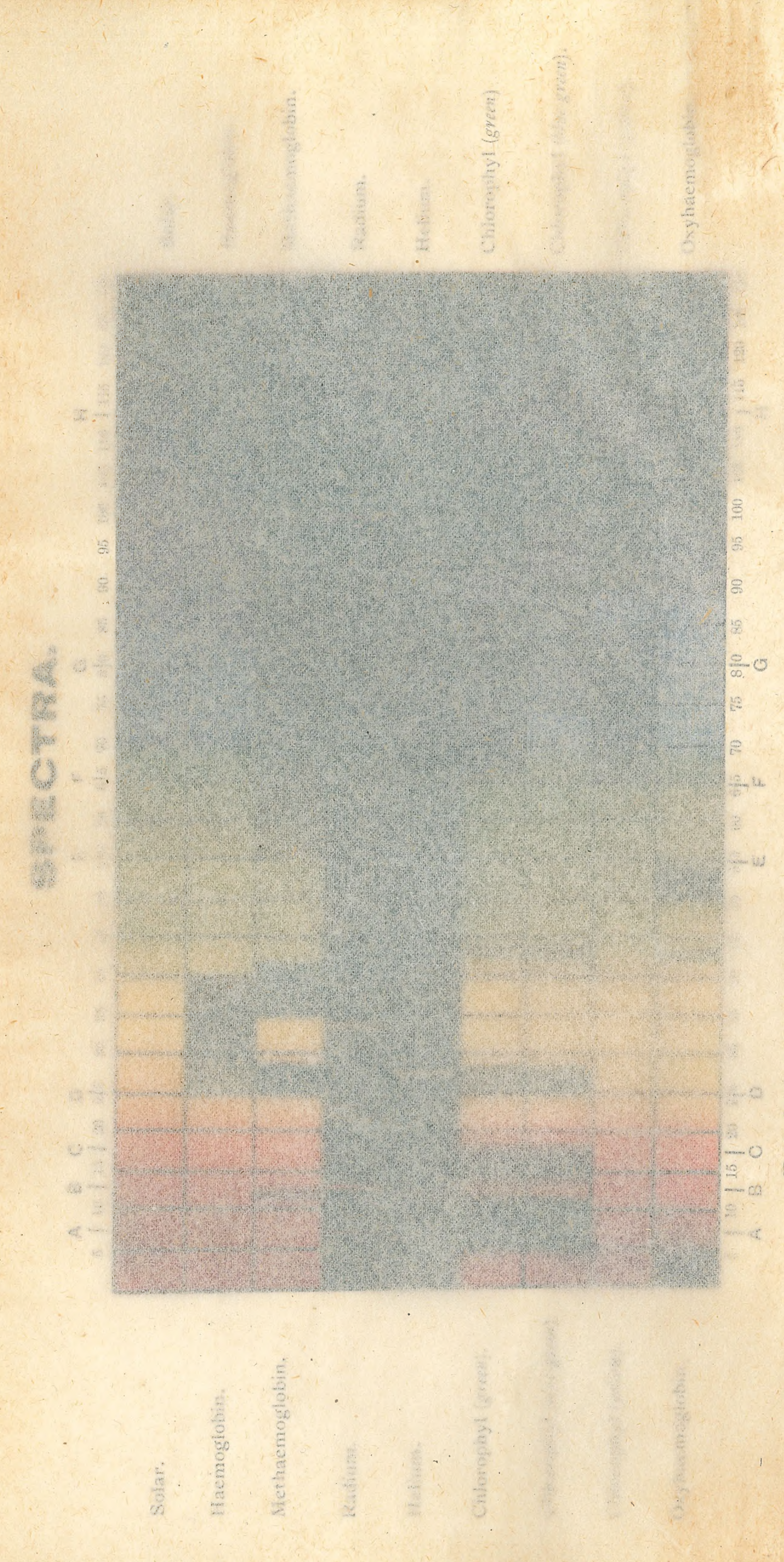

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Fellow of the New York Academy of Medicine; Fellow of the American Electro-Therapeutic Association; Member of the New York County Medical Society; Fellow of the Société Française d'Électrothérapie; Fellow of the American Electro-Chemical Society; Member of the Society of American Authors; Member of the New York Electrical Society; Professor of Light Energy in the New York School of Physical Therapeutics; Late Instructor in Electro-Therapeutics in the New York Post-Graduate Medical School

WITH NUMEROUS ILLUSTRATIONS IN THE TEXT AND A FRONTISPIECE IN COLORS

"But if darkness, light and sight be separate and independent one of the other, then if you remove light and darkness, there is nothing left but void space."—*Buddhistic Sutra.*

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TO THE MANY STUDENTS

FROM ALL PARTS OF THE COUNTRY WHO HAVE SOUGHT INSTRUCTION AT THE AUTHOR'S HANDS, AND WHO HAVE BEEN AT ONCE AN INSPIRATION AND A STIMULUS, THIS VOLUME IS DEDICATED

PREFACE.

The subject matter of this volume on Light Energy, as applied to medicine, has been the outgrowth of eleven years' clinical experience with that part of the subject covered by light.

Its formal presentation to the profession is due to the constant demand on the part of physicians seeking post-graduate instruction at the author's hands that she should embody her experience in the form of a book.

Its pages are devoted to a practical consideration of the physics, physiological action and therapeutic effect of light energy from both natural and artificial sources, and also aim to give a compendium of the literature of this new subject up to date of going to press.

Vacuum tube discharges and radio-active substances are also considered from the physical, physiological and therapeutic points of view.

The Roentgen ray has not been considered, although properly belonging to a consideration of light energy, for the reason that the subject has been most exhaustively covered by others, and books on Radiotherapy exist in sufficient numbers. The Roentgen ray is, therefore, referred to only incidentally in its relation to light and radio-active substances, in order to establish as clearly as possible the indication for the one or the other. In the therapeutic uses of etheric vibrations, differing only in degree not kind, it is difficult to draw a line of demarcation, to say when the irregular discontinuous impulses of the Roentgen ray, itself of the nature of a single ultra-violet ray, should be used, and when the rhythmic orderly procession of the short

high-frequency vibrations of intense chemically active light is indicated. The author will feel that her labor is not in vain if the indications at least for the use of light energy are clearly set forth.

No apology is offered for considering at length the fundamental physics of light energy, especially in so far as the physical laws governing light bear upon its therapeutic application. To those more or less familiar with the subject, it may open up a line of study fascinating in the extreme. The electric arc has been treated of in considerable detail, as upon it the physician's main dependence must be placed for a source of artificial light rich in chemically active energy. The effort has been to elucidate those points only in its physics which her own personal experience in its use had indicated as essential.

The author's own methods of utilizing light energies with results have been given, and also the experiences of others as well. Every opinion formulated by others has been carefully analyzed, and the conclusions drawn therefrom submitted to vigorous criticism, especially from the physical side, before giving them place in these pages. Especially has care been taken to exclude any evidence not based upon sound fundamental physical laws. It matters not what form of energy is expended within the tissues, if the fundamental physical laws of that energy are known, and its physiological action, the therapeutic application becomes a very simple matter, involving no other principles save those fundamental to the physician.

Upon physical laws and properties, physiological action and pathological conditions, the exhibition of light energy is at once rational and comprehensive.

Light as a therapeutic measure, as well as a factor in hygiene and sanitation, is not only of importance to-day, but always will be.

In view of the fact that the continued existence of the human species on earth depends entirely on radiant energy, no apology is necessary for presenting a volume devoted

entirely to a discussion of light in its physical, physiological and therapeutical aspects to the consideration of a profession whose duty it is to minister to human life from its first inception to its final dissolution.

While light energy is as old as the sun, and so almost are its therapeutic uses, never in the history of medicine was it as fully appreciated as now. The author hopes that a study of these pages will teach the student that it is not only ultra-violet energy, but all the radiant energies of the sun or artificial sources of light which are necessary to the maintenance of health, and to the curing of disease. She also trusts that a perusal of these pages will stimulate a careful and systematic investigation of the subject, to the end of placing the general use of light energy upon a foundation equally scientific and sure, as that upon which Finsen has builded his therapy of skin diseases.

The author's acknowledgments are due to the courtesy of Dr. Gunni Busck, of the Finsen Lysinstitut, for the page proof of his work on Light Biology, which arrived in time for the incorporation of the most recent work upon sensitization of living tissues, and also for his hypothesis as to the sensitization of the organism by quinin in malaria.

The author's kindest and most cordial acknowledgments are due her friend, Dr. Elizabeth Stow Brown, not only for assistance in French translations, arrangement of accumulated data and reading of manuscript, but for her intelligent interest in the subject.

The author's acknowledgments are due to the courtesy of the *British Medical Journal* for the use of the cuts (Figs. 4 and 5) illustrating the experiments of Bernard and Morgan.

The author's acknowledgments are also due her friend, Dr. Leslie J. Meacham, for his untiring and intelligent assistance in revision of manuscript and proof.

MARGARET A. CLEAVES.

616 Madison Ave., New York City.

Sept. 15, 1904.

CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I.

Introduction: Light Energy, the Theory of. Its Manifestations, Radiant Heat, Brush Discharges in Vacuum, Visible Light, Ultra-Violet Rays, N Rays, X Rays, Cathode Rays, Alpha, Beta and Gamma Rays.

Light Energy.

Energy is defined by Professor Barker "as a condition of matter in virtue of which any definite portion may effect changes in any other definite portion." It is regarded as the potential of the universe, and when matter is in a phase permitting activity, all other quantities of a matter at a distance are affected. The method of transfer of energy through space is universally conceded to be by means of wave motion through the ether, the eternal recipient and universal transmitter of Nature's infinite energy. Throughout space all matter is vibrating from the lowest musical note to the highest pitch of the chemical rays. The various manifestations of energy known as sound, heat, light, electricity and chemical action, are all vibrations of this universal, homogeneous, incompressible continuous body, which is incapable of being resolved into simpler elements or atoms.

These various manifestations of energy are recognized as such according as they are perceived by different nerves, for the mind of man translates the impressions of the world into facts of consciousness and thought by means of the

nerves of the human body. All these varying rates of vibration, differing as they do only in direction, rate and frequency, are interpreted according to the different nerves or groups of nerves physically attuned to them, or organized to select and respond to especial manifestation of vibratory activity. The optic nerve transmits to the retina and the brain the sensation of light, and its function is limited to the phenomena of radiation. It is wonderfully sensible to certain impressions of this class, but on the other hand is very little affected by, even obtuse to other impressions. Vibrations which affect the sense of touch, taste, smell or the senses can be educated to take the place of the optic nerve to a very great extent, functioning in such a way as to carry correct impressions, ordinarily received by way of the optic nerve, to the brain. Nor does the optic nerve perceive the entire range of radiation. Its function is not excited by all the rays which reach it, while there are others which never reach it at all, being absorbed by the humors of the eye, and producing thereby the brilliancy characteristic of it. Invisible rays are emitted by non-luminous bodies, as there is no body in nature absolutely cold, and every body not absolutely cold emits rays of heat. But in order that radiant heat may affect the optic nerve a certain temperature must be reached. As the temperature is increased, in a platinum wire, for example, through which a gradually increasing current is sent, the wire, by reason of its great resistance, first becomes warmer to the touch, then increasingly warm, next glowing with a red light, and as the current is increased becoming brilliantly incandescent.[1] This phenomenon, which is comparable to the light of the sun, affects the retina and excites the sensation of vision.

The author's conception of light and its action is based upon the now accepted undulatory theory, and is coupled with the belief that all space is saturated with the inconceivably minute corpuscles discovered by J. J. Thomson.[2]

[1]Tyndall: Fragments of Science "Radiation."
[2]J. J. Thomson: Conductivity of Electricity through Gases.

These are regarded as either electricity in its ultimate refinement, as very closely allied to it, or its immediate carriers. The "corpuscle" of Thomson is only the one-thousandth part of the mass of any known particle of matter. The astro-physicists, who accept the corpuscular theory, believe "that the earth and sun, all suns and dark bodies in space, all granular matter, move through the primordial cosmical mass of electrical corpuscles as would a wire screen through water."[1] These bodies, smaller than atoms, are able to pass through the wide spaces, comparatively speaking, of diamonds, glass, steel, flint, etc.

Thomson's corpuscles are positive, and negative in their electrical discharges, the positive carriers of electricity having a size comparable to ordinary atoms of gross matter, but the corpuscles that flow between the atoms of all types of matter are negative. Matter in a state of activity sends out continuously the same kind of corpuscles that fill all space. The sun in its never-ending state of activity, turbulent, tossed into fantastic shapes, is to be regarded as a source of negatively electrified corpuscles which stream through the solar system.

The most intense radiance known is that of sunlight, and when put in candle-power, the figures are so enormous as to convey but little idea to the mind of its intensity. 1,575,000,000,000,000,000,000,000,000, or fifteen hundred and seventy-five billions of billions enumerated according to the English method.[2]

Langley made a careful comparison between the solar radiation and that of the blinding surface of the molten metal in a Bessemer converter. The brilliancy of this metal is so great that the dazzling stream of melted iron, which is poured in at one stage of the proceedings to mix with the metal already in the crucible, "is deep brown by comparison, presenting a contrast like that of dark coffee poured into a white cup." In conducting his experiments every advan-

[1]Larkin: Radiant Energy.
[2]Young: The Sun.

tage was given to the metal in order to institute a comparison between the brilliancy of the metal and the sunlight. No allowances were made for the losses encountered by the latter during its passage through the smoky air of Pittsburgh to the reflector, which threw its rays into the photometric apparatus. Despite this disadvantage the sunlight came out five thousand three hundred times brighter than the dazzling radiance of the incandescent metal.

The radiant energy falling upon the deck of an ocean liner is sufficient, if it could be utilized, to propel the ship with greater speed than is now obtained from carbon, if the radiation received were not cut off by the air. The air cuts off fully one-third.

On an ostrich farm in South Pasadena is a great solar motor which has an indicated output of 11 horsepower, with 210 pounds of steam, which can pump water at a maximum rate of 1,400 gallons per minute.[1]

The inconceivably rapid and minute oscillating light corpuscles of the invisible region beyond the violet have a chemical energy so intense as to destroy micro-organic life, to wreck the molecules of nitrite of amyl, of iodine vapor, to produce erythema of the skin and underlying changes; effects dependent upon the accumulation of the periodical strokes of their oscillating swing until the atoms upon which their timed impulses impinge are jerked asunder. It is this energy in its various manifestations to which this volume is devoted. When light is conceived of in this manner, the reason for its power in continuing life and in curing disease becomes evident at once.

Theory of Light.

Various hypotheses have been formulated in order to explain the origin and transmission of light.

The most important of these are the *emission* or *corpuscular* theory and the *undulatory* theory.

[1]Larkin: Radiant Energy.

On the emission theory it is assumed that luminous bodies emit, in all directions, an imponderable substance which consists of molecules of extreme degree of tenuity; these are propagated in right lines with an almost infinite velocity.

On the undulatory theory of Huygens, light consists of wave motions of the ether, the vibrations being transmitted from particle to particle with an extremely high velocity in straight lines; the vibrations of the particles of the ether are at right angles to the path of the ray.

An idea of this wave motion may be given by shaking a rope at one end, the vibrations, or to-and-fro movements of the particles of the rope are at right angles to the length of the rope, but the onward motion is in the direction of the rope's length.

The luminosity of a body is due to an infinitely rapid vibratory motion of its molecules which, when communicated to the ether, is propagated in all directions in the forms of spherical waves, and this vibratory motion, being thus transmitted to the retina, calls forth the sensation of vision.

The emission theory was supported by Newton, and is spoken of as Newton's corpuscular theory. Euler enunciated the undulatory theory subsequently to Huygens. Since the discovery of the Thomsonian corpuscle and radium the question has arisen as to whether there will not be a reversion to the emission or corpuscular theory. The undulatory theory stands, however, and upon it many optical phenomena, particularly those of diffraction, as shown by Young, can be explained. Energy is the potential of the universe. When matter is in a phase permitting it to be active other quantities of matter at a distance are affected. This transfer is known to be by means of wave motion. Each separate impulse moves from the emitting to the receiving mass on a rigorously straight line. One individual continuous set of oscillations in this straight line is called a ray. If all space is saturated with the inconceivably minute cor-

puscles of Thomson, as there is reason to believe, each negative Thomsonian corpuscle makes a double vibration to and fro like a pendulum (the transmission to-and-fro of the rope illustration) straight across the direction of the ray, i.e., at right angles to it. The corpuscle moves over and returns to the position it had originally before the excursion. After one corpuscle makes an oscillation across the direction of the ray and returns the next does likewise, and the next, and so indefinitely. After the first corpuscle makes a swing, another distant from it 186,000 miles will also make a vibration at the end of the first second of time in the same straight line.

Since these Thomsonian corpuscles are negative and can be drawn out of their original straight path by the action of magnetism, the entire wave motion of the universe is electro-magnetic. This, says Larkin, whose description of the movement of the oscillating light corpuscles is given, was prophesied by Maxwell forty years since. The fulfilment of the prophecy was left to Thomson. There is really no such thing as a ray of light, nor for that matter of pencils consisting of a number of rays. The straight line along the middle of a wave or set of waves as illustrated by the length of the rope is simply to indicate the direction of the waves, and in a graphic representation it also serves to show the amplitude on either side of the frequency of the oscillating light corpuscle. The amplitude is the distance of the sides of the waves from the illustrative central line of the ray. It represents the distance of the swing of the corpuscle on each side of this imaginary straight line.

As each wave is 186,000 miles distant from its source at the end of one second, there must follow variations in the length of the waves. Those of the greatest amplitude, i.e., distance of swing of the oscillating light corpuscle from this straight line, will of necessity be the longest, fewer in a centimetre, because of the space required for them to swing.

Light Energy: Its Manifestations.

Since Roentgen's discovery in 1896 a host of radiations have sprung into prominence, many of which have a relation to physiologic processes, and are applicable to therapeutics. Among these may be enumerated radiant heat, brush discharges in vacuum, light, ultra-violet rays, N rays, cathode rays, X rays and the alpha, beta and gamma rays of radioactive substances.

These latter will receive especial consideration in a subsequent chapter devoted to that subject, and their identity with rays emanating from other sources set forth. All these radiant phenomena are vibrational activities of the all-pervading ether and their differences physically, chemically and physiologically are due to their varying rates of frequency.

As with electricity so with light. There is an enormous range of frequency available. These varying rates of vibrational activity are not all continuous. In the lack of continuity the X ray differs essentially from rays of the continuous solar spectrum.

While it has not yet been proved it is probable that the slowest waves which go around the earth are due to the electric waves from the sun. Then come what are called Langley waves, radiant heat waves, Paschen's waves, and waves which get shorter and shorter, the luminous waves, i.e., the different colored waves of the spectrum, N rays. and, finally, still shorter waves, and at the higher frequencies of the ultra-violet region up to the Becquerel or X rays.

The cathode rays are of a different order, and consist of negatively charged particles or corpuscles, as Thomson calls them. These are the electrons of Crookes. They move with the velocity of from 1-5 to 1-3 that of light. The corpuscle with its charge is identical with the electron. Thomson's corpuscles are positive and negative in electrical charge, the positive carriers of electricity being comparable in size to ordinary atoms of gross matter, the negative cor-

puscles flowing between the atoms of all types of matter very minute. By their impact against obstacles, the target of a Crookes tube, they produce Roentgen rays. Becquerel rays, discovered by Becquerel in his experiments with uranium nitrate, were at first supposed to be different from Roentgen rays in being capable of polarization and refraction. This supposition of Becquerel's, both he and others subsequently disproved. They are also identical with the penetrable radiations of radio-active substances. All the phenomena considered, therefore, may be regarded strictly as manifestations of light.

Radiant Heat.

Radiant heat, considered in its proper place in its physical, physiological, and therapeutic relation, is another manifestation of light energy.

Radiant heat differs essentially from hot air. A thermometer exposed to radiant heat gives no trustworthy indications.

Powerful as these rays are, and sufficient to fuse many metals, they can be permitted to enter the eye and break upon the retina without producing the least luminous impression. Gather them in a focus and there is nothing to be seen at the place of convergence. With a proper thermometer it could be proved that even the air at the focus is just as cold as the surrounding air. The deduction from this is that the ether at the focus is practically detached from the surrounding air, that the most violent ethereal motion may there exist without the least aerial motion, invisible, yet the thermal energy is sufficient to raise iron to a temperature at which it throws off brilliant scintillations.[1] In the invisible region below the red, before the swings or excursions to and fro of the particle of iron become rapid enough to emit dull red, waves are issuing which are too long and slow to have effect on the retinal nerves. The

[1]Tyndall.

atoms of some bodies refuse to partake of motion of the powerful waves of low refrangibility and, therefore, remain unaffected by their heat. Such is not the case of the tissues of the living organism. Upon it radiant heat exercises a profound influence, producing an effect beyond the skin by entering the body as a radiant force. Through the large superficies acted upon there are sent co-extensive ingoing impressions to nervous centres from which they are reflected to the various internal organs.

Langley, with his bolometer or platinum nerve, has investigated this end of the spectrum, and his map of the infra-red end of the spectrum is 13 times as long as that of the visible spectrum.

The waves or frequencies manifested as radiant heat have varying intensities out to the extreme limit. This part of the spectrum is full of lines and bands which vary as much in width as do those of the visible spectrum. They indicate absorption, for absorption is the cause of all dark and cold spaces in the solar spectrum. Cold in this part of the spectrum corresponds to darkness in the visible.

The bolometer or platinum nerve shows itself more sensitive in detecting the long and slow waves beyond the red than the eye, just as the fluorescent screen slows down the waves beyond the fastest violet or the ultra-violet, rendering them visible. The human nerves, to the human sense most exquisitely sensitive, are not, therefore, as sensitive as supposed, for platinum and silver are both more sensitive.

Brush Discharges.

There proceed from the sun magnificent waves, one oscillation in 6½ seconds producing another oscillation. In the earth, however, the frequency of an electric oscillation is 17 per second. But electric oscillations may be made to run up to 50,000 millions per second, while with suitable Leyden jars appropriately connected with a source of E. M. F. the frequency may run up to 30 and 100 millions. Every oscillation of the discharge between these jars sends out a

wave, like a stone falling into water. But if the two discharging knobs be drawn far enough apart there is no longer sufficient potential of this miniature lightning discharge to break down the air, so it expands into a brush of blue light—electricity—like the brushes of a paint brush if widely separated. This constitutes the brush discharge, and in nature it finds its counterpart in aurora. To every one familiar with the phenomenon of this discharge from high tension coils or from Holtz machines the absolute identity of the two phenomena is at once apparent. "The light of the aurora, although caused by the sun, does not come direct but is caused by the turbulence set up in the earth's magnetic field by electro-magnetic upheaval on the sun. The field of the earth is tuned for that of the sun, as are coherers in sympathetic telegraphy and telephoning. The phenomena of the aurora are electrical, affecting magnets and compass needles on ships." So also is the brush discharge. In this connection this discharge concerns us not as it streams from the terminal balls of the discharging rods when there is no longer sufficient potential to cause a disruptive discharge, nor as it streams from the edges of the insulating platform nor from wooden balls and points, but when discharged in vacuo. These tubes when connected by their platinum terminals to an excited static machine or a high tension coil glow with supernal radiance. The light oscillates with great rapidity. In their behavior they have been likened to the oscillating discharges of the "auroræ hung up above the poles of the earth." The phenomena occurring in these tubes of varying degrees of vacuity "are in that mystical place, the dim borderland between radiant energy and radiant matter if indeed there is any boundary between, for Thomson's corpuscles and Crookes' electrons, although matter, behave like radiant energy."

These discharges, electro-magnetic, present then the phenomena of light and electricity. They are chemical in their action, and the frequencies of the light energy vary

according to the degree of vacuum. The theory of these discharges in vacuum, as well as their physiological and therapeutic applications, assume their place in Chapter XVII.

Luminous or Visible Rays.

Ascending the scale or heating the iron still hotter than for the purposes of heat emission only a dull red appears. By increasing the heat, there will develop all shades of red from a dull to a bright color. If these rays be reflected through a prism upon a white screen a band of red light will be seen extending from a deep to a bright red. It is not hot enough to emit other than red, that is, its particles do not oscillate fast enough to send forth any other lengths of waves. If the iron is heated still hotter until it loses its red color and becomes white, if reflected through a prism upon a screen, a continuous spectrum will be seen. A still more intense heat and the color band still complete becomes brighter than before. This spectrum is continuous because all the frequencies from the long and slow of the red on up to the orange, yellow, green, blue, indigo and violet, diminishing gradually in length and increasing correspondingly in frequency, and of gradually diminishing amplitude, are present.

When an inch contains from 36,000 to 61,000 of these electro-magnetic undulations their effect upon human sensation, by reason of the retina, is that of light. Their number compensates for their minuteness. Trillions of them enter the eye and hit the retina in the time consumed in the utterance of the shortest sentence.

The shortest violet wave, just before extinction in the ultra-violet region, is of such lengths that 61,000 are within one inch. As illustrative of the extreme shortness of these waves is the fact that the highest musical sound caused by an oscillating piano wire 4,000 times per second is conveyed by a wave 3 1-3 inches long. All sound waves are, however, extremely long as compared with light waves.

This continuous spectrum has been likened to the keyboard of an organ with every key open, the bellows being in constant action, the bellows corresponding to the continuous shining of the sun or other sources of white light.[1]

The continuous spectrum is very valuable in its physical, physiological and therapeutic relations. This is not only true of one region or one color, but of the complex of frequencies of which it is made up.

Ultra-Violet Rays.

Bordering on the extreme end of the violet of the continuous spectrum is that mystical region, the ultra-violet. It has been and is the subject of constant study and interest to the physicist, and is constantly being explored with intense interest. Since the work of Finsen it has been of great prominence in the medical world. The absence of strict scientific knowledge of the nature of the inconceivably rapid oscillations of the light corpuscles of this region, invisible to the eye save as made visible by a fluorescent medium or in their appeal to the imagination, caused results obtained from sources of light energy, absolutely barren of ultra-violet manifestations, to be attributed to them. More, the physiologic phenomena and therapeutic results from the use of various sources of light energy have been misinterpreted, and results obtained from the use of light, whether from the solar light sifted through a glass lens or an incandescent light with a blue glass enclosing bulb, have been attributed to ultra-violet light energy, although these rays have been absorbed by the intervening medium of glass in both instances, and very feebly generated, if at all, in the latter instance. The complex of light energy and its relation to therapeutic result, has not been correctly interpreted and analyzed. Valuable as are these invisible frequencies,

[1]Larkin: Radiant Energy.

their value is greater when associated with the blue violet of the continuous spectrum or its entire radiance. In its appropriate place, ultra-violet energy receives full consideration from the physical, physiological and therapeutic points of view. The detailed physics of ultra-violet frequencies, of unsurpassed interest, as for that matter is the physical side of all forms of energy, is taken up in connection with their physiologic and therapeutic action in an especial chapter rather than under the general physics of light energy. It is not that ultra-violet frequencies are to be disassociated from the spectrum, but quite the contrary.

By the increased temperature of our illustrative iron the excursions to and fro of the oscillating light corpuscles become faster and faster, and with their increased rapidity the amplitude of their swing from side to side is correspondingly lessened. The length of the spectrum beyond the measured ultra-violet is still unknown, but it seems certain that these invisible frequencies become shorter and shorter until they are merged into Roentgen waves.

The N Rays.

According to the latest report the N rays discovered by Blondlot take their place in the violet region of the spectrum.

As yet there exists a great deal of scepticism as to their existence. They are by no means impossible, they are even probable, but they are not yet an established scientific fact. It would not be strange if a chemism such as the living organism should emit rays of some nature. There is considerable collateral scientific fact to support this view. Suffice it to say if the existence of rays emanating from the human body or tissues is proved, it is quite likely that they will become of equal if not of greater importance than any of the other rays. The discovery, nature and relation of these rays to the living organism are considered especially in a subsequent chapter.

Roentgen or X Rays.

A beam of light which has passed through a prism is bent aside, or refracted.

To the question why are these waves bent differently when they strike a piece of matter obliquely, the answer has been given by distinguished physicists, Stokes, Lord Kelvin and others, because of the heterogeneity of matter. Matter is composed of particles or atoms or molecules of infinite size not incomparable with the size of the waves. In the homogeneity of matter, that is, with all its parts similar, as is the case with ether, there would be no such dispersion or sorting out of the waves. They might be bent, but they would not all be bent alike. Dispersion, or separation of the waves, into their different sizes depends upon the size and oscillation frequency of the atom. The size of the atom can be estimated by the amount of dispersion. Were the atoms either enormously larger or extremely smaller than light waves, then there would be no dispersion. But if they are at all comparable in size, then the waves which are similar to them in size are most affected. As the atoms are much smaller than the waves the greatest effect is upon the blue-violet and ultra-violet.[1] They are more nearly in sympathetic resonance with them, and it is for this reason that physically these frequencies are capable of influencing most profoundly molecules or groups of molecules in the living organism. The longer and slower frequencies, from the green down to the infra-red, are much less affected. Until the discovery of Roentgen the spectrum was limited by the ultra-violet.

According to Helmholtz' theory of dispersion, the existence of still smaller waves would ultimately give waves smaller than atoms. This being the case these waves would be bent less, not more, and the result would be a reversal

[1]Sir Oliver Lodge: Archives of Roentgen Ray. March to June, 1904.

of the dispersion of the upper part of the spectrum. In other words, the spectrum would be folded back upon itself, and when the infinitely small waves were reached they would not be bent at all, but would go straight on. From this theory of dispersion it is, therefore, clear that starting at the lower end of the spectrum, where the waves are infinitely long, the spectrum would double back upon itself until the waves would be comparable to an atom in size, so that ultimately from the shortest possible waves there would be no bending at all. In the X ray, Helmholz' mathematical theory finds its proof.

They are very rapid, excessively short, smaller in fact than anything conceived of before. They are not bent and they go straight on. In this going straight on without any deviation they are distinctive from the ultra-violet ray. Still further, unlike the rhythmic continuous movement of light or, in this especial comparative instance, ultra-violet light, they are discontinuous, and as yet there is no means of rendering them continuous. They are a single solitary ether pulse, up and down almost instantly, and then cessation. They may be likened to an energetic whip crack, a falling of a brickbat, a jangle, not a harmony coming again and again but infrequently once in a thousand years or so in the life of an oscillating ultra-violet wave.

The X ray proceeds from the target with every blow of the electron, and in rapid succession as the target is being bombarded by the electrons or cathode rays in very large numbers.

In the inconceivably small size of these waves, in their suddenness, so to speak, and infrequency, they probably act physically to reinstate the vibrations of atomic structures in diseases not yet wholly departed from their normal period of vibration.

The property of ionization is possessed in common by ultra-violet, cathode and Roentgen rays.

Cathode Rays.

In the dark space of a vacuum tube the most interesting phenomena take place. It is where the cathode rays are formed. These cathode rays are particles of electricity shot off from the negative terminal. They are really the negative corpuscles of Thomson. A ray in the mind of the physicist is generally associated with an undulatory motion of the ether. This, says Thomson, is only an accidental association, and there is no necessary connection between a ray and undulatory motion. Those negative corpuscles or cathode rays have an extraordinary resemblance to the conditions postulated in the corpuscular theory of light. They travel in straight lines, they are shot off with tremendous speed, a speed able to carry them about 20,000 miles per second from the negative terminal, or cathode of a Crookes tube. Cathode particles have been observed in a tube having a velocity as much as one-third of light. In their very high speed they are comparable only to light.

Mass of a Negative Corpuscle.—They have but small mass weighing much less than an atom. The mass of each of these particles is only about one-thousandth part of that of the atom of hydrogen, the smallest mass recognized before Thomson's discovery.

Emission of Cathode Rays by Radium.—There are some substances which are perpetually emitting cathode rays, notably, as was shown by Becquerel, uranium and its compounds. Radium, however, possesses this property to an enormously greater extent than excited Crookes tubes.

Velocity Greater from Radium. — The velocity with which the corpuscles are emitted from radium is about two-thirds that of light, and is double the highest velocity which Thomson, in his experimental work, was able to obtain in an exhausted tube excited by the most powerful induction coil.

Phosphorescence Excited by Cathode Rays.—When the residual gas is removed they will infringe on the walls of the tube and make them phosphorescent. The phosphorescence

of the glass produced by them is not a unique one, as it is shown by many substances. Rock salt becomes a pretty violet blue under their influence, and if kept dry, will last a long time. Glass is changed by a long exposure and loses its power of phosphorescence. In other words, it becomes tired, as it were, under the excessive bombardment.

Thermal Effects Produced by Cathode Rays.—Bodies upon which they fall are heated by cathode rays, and if concentrated by using a portion of a hollow cylinder or spherical shell as a cathode, platinum may be raised to incandescence, thin pieces of glass fused and diamond charred by them. The energy possessed by the corpuscles striking the body Thomson estimates at nearly two calories per minute.

Production of Roentgen Rays by the Impact of Negative Corpuscles.—The most widely known property of the cathode rays is that of producing the Roentgen rays. They are the parents, so to speak, of the Roentgen rays, for the latter are produced whenever the cathode rays strike against a solid obstacle.

By the use of a platinum target in a Crookes tube, the cathode rays are stopped and the X rays produced. It is not that the cathode rays are reflected, but as every single negative corpuscle strikes the target there is emitted by the sudden stoppage of the electric charge a single wave. "Just as the disturbance made by shaking a whip travels down the whiplash, so each of these cathode rays as it stops gives an ethereal crack as it were." These "ethereal shells," or solitary pulses, are excited by the impact of the cathode rays upon the target, just as sound or heat is caused by the impact of the bullet.[1]

Lenard's Experiment; Transmission of Cathode Rays.—Lenard's discovery, just antedating Roentgen's, consisted in bringing cathode rays outside a vacuum tube. "Before this the cathode rays could not be used for a therapeutic

[1]Sir Oliver Lodge.

purpose."[1] By facing his vacuum tube with a very thin piece of aluminum foil Lenard succeeded in getting them out. These rays are penetrating enough to get into ordinary air, but they are stopped by ordinary matter. Aluminum stops them less than any other solid matter. At the time of Lenard's discovery, the strange effects of these penetrative aluminum rays received but little attention.

Similar Effects to Roentgen Rays.—After Roentgen's discovery they came more into prominence, and the effects were found to be precisely similar to the effects of the Roentgen rays, with, however, slightly different properties. They are similar in their (1) penetrative effects, can go through metal; (2) ability to affect photographic plates; (3) to discharge Leyden jars; (4) to make gas, through which they pass a conductor of electricity; (5) production of phosphorescence in substances against which they strike.

Although capable of producing photographic effects, radiographs cannot be produced by them, as the flesh arrests them and prevents the showing of the bones.

Cathode rays outside the tube are, therefore, called Lenard's rays, as he was the first physicist to cross the Rubicon between the inside and the outside of a vacuum tube.

Thermo-Luminescence Produced by Cathode Rays.—Cathode rays produce in some substances, discovered by Professor E. Wiedemann, a thermo-luminescence. For example, a mixture of sulphate of calcium with a little sulphate of manganese is not altered in its appearance by the rays, but for some time after its exposure it bursts into a vivid greenish glow when slightly heated.

Mechanical Effects Produced by Cathode Rays.—Other than the properties possessed in common with the Roentgen rays, cathode rays have the property of producing motion of objects against which they strike. This is very prettily shown in the experiment due to Sir William Crookes, with a little mill having a series of vanes, the axle of which is

[1] Sir Oliver Lodge.

mounted on glass rails within the vacuum tube. When the discharge passes through the tube the cathode rays strike against the upper vanes, and the wheel rotates and travels from the negative to the positive end of the tube. At the same time, if the vanes are covered with suitable media they show a beautiful phosphorescent gleam.

Electric Charge Carried by Cathode Rays.—Cathode rays carry a negative electric charge, and the negative electrification follows the same course as rays producing phosphorescence on the glass.

Gas through which Cathode Rays Become a Conductor of Electricity.—In their passage through the rarefied gas of the tube they change it from an insulator to a conductor of electricity as soon as it is traversed by them. The cathode rays really constitute an electric current, they are really electrons in rapid motion. For that matter any electric current consists of electrons in rapid motion. They cannot be seen as in high vacuum because they are not usually free to move. A stream of electrons may be driven down a conductor in such a manner as to show that they are producing current. This was done by Faraday years ago, who did not know, however, what was occurring. As they pass from hand to hand, as it were, by the atoms of a metal chain they may be likened to a chain of buckets as they are passed along a chain of persons at a fire. As they proceed down the whole of the matter conveying them can be deflected by a magnet.

The discovery of the true nature of the cathode rays and the existence of electrons or particles of electricity, has made electric conduction and electric action generally much more definite than before.

Reflection of Cathode Rays.—This is not reflection as understood in optics. It is called diffused reflection of the cathode rays. When cathode rays strike the surface either of a conductor or an insulator, cathode rays start from the surface in all directions. All the rays then proceeding from a surface struck by cathode rays are called reflected.

Magnetic Effects of Cathode Rays.—By the luminosity produced in this way their path, ordinarily a straight line, becomes curved when exposed to the action of a magnet. A practical application of this fact is made in electrical engineering in the study of rapidly changing magnetic forces. Ordinary magnets are too heavy to follow the vagaries of the magnetic course, but the cathode rays, having practically no mass, are able to follow the changes in the force no matter how rapid they may be. By watching the movements of the rays the behavior of this course can be deduced.

Magnetic Spectrum of Cathode Rays.—When cathode rays are produced by an induction coil which gives a discontinuous discharge the phosphorescence is broken up into several distinct patches by a magnetic field. For example, if originally there is a narrow straight band of phosphorescence, under the influence of a magnetic field several bright bands of phosphorescence separated by dark spaces are observed. This is the magnetic spectrum of cathode rays, when not produced by mechanisms which have a continuous E. M. F., as an electro-static machine or a storage battery.[1]

Repulsion of Cathode Stream.—When there are two cathodes in a vacuum tube connected together, the cathodic rays from one cathode are deflected when they pass through the dark space surrounding the other cathode. This is to be explained by the electrostatic repulsion of the negative electricity travelling along the cathode rays, by the strong electric field which surrounds it.

Canalstrahlen or Positive Rays. — The Canalstrahlen were observed experimentally when a perforated cathode was used. Under these conditions, if the pressure was between certain limits, luminous streams were observed passing through the holes in the cathode, travelling in straight lines and emerging on the side of the cathode remote from the anode.

These excite phosphorescence on the part of the glass

[1]Strutt: Phil. Med. Mag., Vol. XLVIII., p. 478, 1899. Quoted by Thomson.

upon which they strike. If the glass is soda-glass, sodium lines will be observed spectroscopically. When they strike a copper plate they oxidize it. This is not due to the impact of the rays, but is an indirect effect due to the rays producing active oxygen when they pass through the gas. They do not exert this reducing effect through hydrogen. The Canalstrahlen consist of positively charged particles. There is thus a stream of positively charged molecules moving toward the cathode, causing this to emit cathode rays. When the cathode is perforated a part of the stream passes through the holes, producing in the gas behind the cathode luminosity, thus forming the Canalstrahlen. This explanation of Thomson, although not given as sufficiently established, is, however, regarded as the correct one.

The velocity of the positive ions is very much smaller than that of the cathode rays measured, while the proportion of electric charge to the mass is only about 1/30000 of the value of a negative ion. It is the same as the value of an electric charge to the mass in the ordinary electrolysis of solutions.

The sun, and probably any luminous star, may be regarded as a source of negatively electrified particles which stream through the solar and stellar systems. When corpuscles moving at a high speed pass through a gas they make it luminous; then when the corpuscles from the sun meet the upper region of the earth's atmosphere they will produce luminous effects. This is the belief of many astrophysicists. If it be assumed that the aurora borealis is caused by corpuscles from the sun passing through the upper regions of the air, its many periodic variations can be explained satisfactorily.

Alpha, Beta and Gamma Rays.

In the sensitiveness of the electroscope to radiations of many kinds radio-active substances were discovered. These are considered at length in their appropriate place.

The emanations from radium are divided into three groups, the alpha, beta, and gamma.

The alpha group consists of emanations not affected by a strong magnetic field, incapable of passing through any but the thinnest material obstruction.

They are the positively electrified atoms, and their mass is enormous as compared with that of the next group.

The beta rays are cathode rays given off from radium at a very high rate of speed, two-thirds that of light. The gamma rays find their counterpart in the Roentgen ray.

In all these manifestations of light, radiant heat, brush discharges, visible light, ultra-violet rays, cathode rays, N rays and X rays, the physician has an interest as well as the physicist.

Electric waves	Un-known	Infra-red	Red	Orange	Yellow	Green	Blue	Violet	Ultra-violet	Hyper-ultra-violet	Roent-gen rays

CHAPTER II.

The Physics of Light Energy and Radiant Heat. Sunlight, Electric Arc Light, Incandescent Light, Mercury Vapor Light, Spark and Vacuum Tube Discharges.

The Physics of Light.

The purpose of this chapter is to present the physics of light as it bears upon its therapeutic uses. It is possible that the limit may have been exceeded, and it is probable that it falls short of much that the student desires to know. These fundamental facts are to be found in every text-book on physics with illustrative diagrams, to which the reader is directed for further investigation.[1]

The physics of incandescent light, ultra-violet light, and fluorescence are considered in detail in the chapters devoted to those subjects rather than in this connection. The mercury vapor lamp gives a powerful chemical light, but owing to its size and shape does not lend itself to therapeutic work. It is briefly considered, however, at the close of this chapter.

Analogy between Sound and Light.—The analogy between sound and light is a very close one. The intensity of a sound is greater as the amplitude of the vibration of each particle of the air is greater, and the intensity of the light is greater as the amplitude of the vibration of the air is greater. The shorter the undulations producing the sound, the more acute it is, or in other words the more

[1]Standard text-books on Physics, Ganot and Daniell.

vibrations there are to the second. Similarly the color of light, or for that matter the invisible waves of light as well, is different according to the length of the undulation producing the light. Red light, for example, is due to a comparatively long undulation and corresponds to a deep sound, while a violet light is due to a short undulation and corresponds to an acute sound.

Perception of Light by the Retina.—The vibrations of the frequencies of the spectrum are perceived by the retina only within distinct limits. If a beam of white light, from the sun, for example, be transmitted through a prism, the light rays are refracted and dispersed, and a prismatic spectrum is obtained. White light when transmitted through a shutter into a dark room and permitted to fall on a screen will form a spectrum, assuming a definite order, i.e., from the least refrangible red to the most refrangible violet.

White light contains, therefore, all the frequencies of the spectrum, the dark or infra-red waves are refracted least, and do not act upon the retina, and are, therefore, invisible. They act, however, upon sensory nerves, and give rise to the sensation of heat. From Fraunhofer's line, A, onward, the oscillations of light affect the retina in the following order and constitute the visible spectrum: red with 481 billions per second, orange with 532, yellow with 563, green with 607, blue with 653, indigo with 676, and violet with 764 billions per second.

The sensation of color, therefore, depends upon the number of vibrations of the light ether, just as the pitch of a note depends upon the number of vibrations of the sounding body. The number of vibrations for each color is constant. There is no color on earth, all colors are in the light, and they manifest themselves as one color or another according to the objects upon which they fall. To perceive a color it is essential that a certain amount of light fall upon the retina. At the lowest degree of brightness, blue gives a color sensation with an amount of light 16 times less than

required for red. White light of different periods of vibration or frequency applied to the eye excites the different sensations of color, the amplitude of the vibrations, height of the waves, or distance of the swing of the oscillating corpuscles from the imaginary line called a ray, determine the intensity of the impression of light, just as the loudness of a note depends upon the amplitude of the vibrations of the sounding body. When all the frequencies fall simultaneously upon the retina, the sensation of white is experienced.

By reuniting the colors of the spectrum obtained by prisms white light is again obtained. If none of the vibrations of light reach the retina, there is what may be termed an absence of sensation of light and color, rather than blackness.[1]

Light Propagated in a Straight Line.—While the propagation of light is always regarded as in an absolutely straight line in a homogeneous medium, the oscillating particles of different rates and length of swing really form curves sinusoidal in character, and if, represented graphically, a single ray of it could be obtained, would practically be that of a sine. The length of the wave is from crest to crest.

The oscillating or swinging corpuscles which represent the vibrations of light are at right angles to the hypothetical line known as ray. With increasing frequency of these oscillations the amplitude of the curves becomes less and the waves shorter. For example, in the same length of ray, a centimetre, a greater number will be contained. A single ray cannot be obtained alone, however, but only pencils consisting of a number of rays.

Parallel, Divergent and Convergent Rays.—If these are at a great distance from the source of light, and the vibrations are very small, they will be parallel. This "luminous pencil," or beam, is, therefore, said to be parallel when it is

[1]Landois and Stirling, p. 982.

composed of parallel rays; divergent, when the rays separate from each other; and convergent, when they tend toward the same point.

The effect of color is produced in the eye by the varying frequencies of the vibrations. For each color the number of vibrations is constant, but in a given medium the wave length differs.

Velocity of Light.—Light moves with such a velocity that at the surface of the earth there is, to ordinary observation, no appreciable interval between the occurrence of any luminous phenomenon and its perception by the eye.

The Transmission of Light Rays.—Through the free ether in a vacuum, and almost equally so in air, light rays are transmitted with equal velocity. The number of vibrations are, therefore, small or great in proportion as the waves are long or short.

The velocity of light is estimated at 190,000 miles, 300,000 kilometres per second, or 30,000,000,000 centimetres per second.[1]

The stars nearest the earth are separated from it by at least 206,265 times the distance of the sun; therefore, the light which they send requires more than three years to reach us.

The visible frequencies are to be found between 763 and 395 billions per second, quite generally given as 760 to 390 billions per second.

Light Intensity and its Laws.—By intensity of illumination is understood the quantity of light received on the unit of surface.

The intensity of light is governed by the following laws:

(1) The intensity of illumination on a given surface due to a point surface of light is inversely as the square is the distance from the source. By doubling the distance the strength of the light is diminished to one-fourth. If it be increased threefold the strength of light is one-ninth. If

[1]Landauer.

the distance be increased four times, the strength of this source of light must be multiplied by 16 in order to gain an equally powerful illumination.

When the effective light rays strike a surface at right angles, the most powerful illumination takes place.

When the illumination is oblique fewer rays fall on the same plane; some of the rays naturally are longer, and, therefore, when they strike the plane, they are also feebler.

The brightness of illuminating bodies depends on their distance from the source of light, and on their position in relation to it as well as upon the intensity of light in each single point, and on the size of the illuminating plane.

(2) The intensity of illumination which is received obliquely is proportional to the cosine of the angle which the luminous ray makes with the normal to the illuminated surface.[1]

It is owing to the divergence of the luminous rays emitted from the same source that the intensity of the light is inversely as the square of the distance. The illumination of a surface placed in a beam of parallel luminous rays is the same at all distances in a vacuum. In air and other transparent media the intensity of light decreases in consequence of absorption more rapidly than the square of the distance. The law of the cosine applies to rays emitted obliquely by a luminous source; that is, the rays are less intense in proportion as they are more inclined to the surface which emits them. They correspond in this respect to the third law of radiant heat.

Light Standards.—There is no absolute unit of either physical or physiological light. There are, however, certain standard sources of light, the intensity of whose light is taken as unity. (1) The British Standard Sperm Candle burning at the rate of two grains per minute. (2) The Vernon-Harcourt-Pentane Standard, in which

[1]Ganot's Physics.

a gas flame of a given height, observed through an opening of definite size, consumes pentane, a variety of coal oil. (3) The Carcel Colza-Oil Lamp, burning 32 grammes of pure Colza oil per hour at a flame height of 40 millimetres. (4) The Hefner Altneck Amyl-Acetate Lamp, in which the flame stands at an elevation of 40 millimetres. The latter is generally known as the German unit, the first as the English unit and the third as the French unit. There are also the Violle Standard Platinum Lamp and the Reichsanstalt Standard, the one depending upon the light emitted by one square of platinum at the temperature of solidification and the other upon the light emitted from a square centimetre of platinum at a definite high temperature.[1]

The eye is not sufficiently accurate to estimate even approximately the relative brightness of the illuminating planes, or in the event of varying intensity of two given points from the same source. For this purpose photometers are used.

Photometers.—By a photometer is understood an apparatus for measuring the relative illuminating powers of different sources of light. With the rays falling perpendicularly upon a unit area, the illuminating power of a source of light is the quantity received by the unit area at unit distance from the source.

Bunsen's Photometer.—The principle of this photometer depends upon the fact that when a grease spot is made on a piece of bibulous paper, if the paper be illuminated by a light placed in front, the spot appears darker than the surrounding space; if, on the contrary, it be illuminated from behind, the spot appears light on a dark ground; if the grease spot and the rest appear unchanged, the illumination on both sides is the same.

With different light intensities this result is obtained by leaving the one stationary and moving the other nearer

[1]Houston and Kennelly: Electric Arc Lighting.

or farther away, when a point will be reached at which the grease spot will become invisible because it will then appear as bright as the surrounding paper.

By measuring the distance of the light from the screen by means of a scale, their relative illuminating powers are respectively as the squares of their distance.

To make these photometric measurements, light of a certain intensity, varying in different countries, as has been quoted, is used as a standard.

Rumford's Photometer.—This consists of a ground-glass screen, in front of which is fixed an opaque rod. The lights to be compared, a lamp and a candle, for example, are placed at a certain distance in such a manner that each projects on the screen a shadow of the rod. These shadows are at first of unequal intensity, but by altering the position of the lamp, the latter may be so placed that the intensity of the two shadows is the same. Then since the shadow thrown by the lamp is illuminated by the candle, and that thrown by the candle is illuminated by the lamp, the illumination of the screen, due to each source of light, is the same. The illuminating power of the two sources, that is, the illumination which they would give at equal distance, is then directly proportional to the squares of their distances from the shadows. Or, in other words, if the lamp is three times the distance of the candle, its illuminating power is nine times as great.

There are quite a number of other photometers with which the reader may familiarize himself by reference to standard books on physics.

Measurement of Light by the Actinometer. — In the actinometer, an instrument is to be had for the measurement of light. That light may be used systematically in order to secure a uniformity of usage, precise dosage is necessary.

The principle of the actinometer involves the play of the rays of light upon a platino-cyanide of barium screen, and then determining the thickness of a solution of ammoniated

sulphate of copper necessary to cut off the chemical frequencies.

It is composed of a little black chamber in brass of cubical form. There is a circular orifice on the anterior part closed by a disc of quartz, which permits the entrance of the violet and ultra-violet light. On the posterior part there is cemented a tube of crystal in which glides, drawn by a rack, a tube of brass closed in its anterior portion by a plate of quartz. This plate is covered on the face that looks toward the interior half with platino-cyanide and half with an absolutely opaque black varnish. A standard solution of ammoniacal sulphate is turned into the apparatus. If this actinometer is directed toward a luminous source, then with a convenient thickness of the absorbent liquid, the luminosity of the half the quartz plate covered with platino-cyanide, which had become fluorescent, disappears. From the thickness of the ammoniated sulphate-of-copper solution necessary to obtain this result, the chemical power of the light source is estimated.

Superimposed strips of sensitive paper are also used to measure chemical light intensity, and observations are taken of the progress of the photographic effect.

Larsen[1] measured the blackening of chloride-of-silver paper as the light passes through.

By adding certain coloring matters to the bromide-of-silver paper they may be rendered sensitive to frequencies of other regions than the blue violet and ultra-violet. This is the case with rhodamin, as shown by Andresen, which is sensitive to yellow light; the bromide of silver remains very sensitive to blue violet, but this is counteracted by the use of yellow filters. The sensitiveness of Andresen's rhodamin—bromide-of-silver paper, as well as of other papers, was proved by Eder in a series of experiments. These showed that certain photometer papers are affected by the different regions of the spectrum, according as they are exposed to a

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[1]Quoted by Freund.

more or less strong light. It is necessary to take into account the concentration and quality of the filtering color used to exclude the blue and violet rays—which become effective with long exposures.

Then again there are electric photometers based on a peculiar property of selenium.

As ultra-violet rays favor the formation of an electric spark, this property has been utilized for the construction of what Larsen, whose device it is, termed an actinoscope. The spark of a static machine or a Rhumkorff coil will cross a longer spark gap if the negative terminal be exposed to ultra-violet energy.

Reflection.—When a ray of light meets a polished surface, it is reflected according to the two following laws:[1]

I. The angle of reflection is equal to the angle of incidence.

II. The incident and the reflected ray are both in the same plane, which is perpendicular to the reflecting surface.

The light which falls on a rough non-luminous body is partly absorbed or transmitted, and the remainder which is thrown back on all sides, makes the object visible. With smooth polished surfaces, however, mirrors, for example, the light is only reflected in certain definite directions. By sufficiently smooth is meant a surface the ridges or scratches of which are decidedly smaller than the wave lengths of light. If they are less than one-quarter of the wave length (less than 1/200000 of an inch) they do not cause any breaking up of the waves, and optically are considered quite smooth. Mirrors are polished by scratching them all over with a very fine powder, which makes scratches finer than 1/200000 of an inch. The perpendicular produced at the point of the reflecting surface where the ray impinges is in the same plane as the incident and reflected ray, and both form identical angles with it.

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[1]Ganot's Physics.

Mirrors in connection with the use of light concern the therapeutist, as they are used with various light mechanism to reflect the light either (1) directly upon the lenses of light-condensing apparatus, or (2) directly upon the surface of the patient's nude body. They are divided according to their shape into plane, spherical (concave and convex), parabolic, conical, etc.

Rays of light which diverge from any point of an object and fall upon a mirror are caused either to converge to, or to appear to diverge from a second point. In either case the second point is called the image of the first point.

Plane Mirrors.—The images of objects in plane mirrors are always exactly opposite the objects, and each is as far behind the mirror as the object is in front. The action is different with curved mirrors, concave and convex.

Concave Mirrors.—A concave mirror, spherical shape, curved and polished on the inside, may produce a real convergence to a point. For example, light reflected upon a concave mirror will converge upon a point in mid air, and that point is the focus. Were it convex instead of concave, the impingement of light waves upon it and their reflection would cause a divergence of the waves. There would no longer be a real focus. Light rays falling on a spherically curved concave mirror, so as to pass through the centre of the sphere, are called axis rays. The spherical centre is called the centre of curvature, and the straight line passing through this point and the curve centre of the mirror itself is the optical axis of the mirror. Axis rays are reflected back directly. The sun's rays coming from an infinite distance are reflected in such a manner that all pass through the focus. This is also the burning point. The focus is the point of convergence of all the rays that strike the mirror parallel with the axis. This focus lies on the main axis, and is midway between the mirror centre and the sphere centre. With the approach of the source of light to the mirror, so that its rays are no longer parallel to each other, the focus recedes further and further, even to infinity. When the source of light is in the focus the reflected rays are then parallel. When the source of light is brought between the focus and the surface of the mirror, they become divergent.

Parabolic Mirrors.—Parabolic mirrors are concave mirrors whose surface is generated by the revolution of the arc of the parabola. All rays after reflection meet in the focus of the mirror and conversely, when a source of light is placed in the focus, the rays incident to the mirror are reflected exactly parallel to the axis. The light thus reflected tends to maintain its intensity even at a great distance, as it is the divergence of the luminous rays which principally weakens the intensity of light. It is because of this property that parabolic mirrors are used as projectors in railway trains, carriage lamps, etc.

The Mangin Mirror.—This dioptric reflector is a glass mirror of special form. It consists of a spherical mirror whose inner and outer surfaces are of different radii. The outer surface is silvered so that the rays proceeding from the arc pass inward, i.e., to the mirror at the back of the mechanism before being projected outward as parallel rays. This is true of all frequencies of more than 30 micro-centimetres in length. Frequencies of shorter length, i.e., the ultra-violet, do not pass outward through the mirror of glass because of their wave length. This is the mirror provided in the marine searchlight mechanism, described in another chapter.

Application of Mirrors.—The application of plane mirrors does not concern us here. Concave mirrors are largely used in therapeutic work: (1) to reflect the light of an arc upon a condensing lens; (2) to reflect the sun's rays or the light of the arc upon the patient's body. Simple concave silvered mirrors are used to reflect the light of the arc in the cabinet devoted to therapeutic work. Concave mirrors serve to concentrate greater quantities of light than can be done with lenses. The mirrors used by Kime for concentrating solar light are of this type. Parabolic mirrors absorb but little light and can be used at suitable focal distances.

Focal Length.—The point of convergence of the parallel rays is the principal focus of the mirror; its distance from the mirror is the focal length.

Refraction.—By refraction is understood the deflection or bending which the rays of light experience in passing obliquely from one medium to another; for example, from air into water. If the incident ray is perpendicular to the surface, separating the two media, it is not bent but continues its course in a straight line. The incident ray is the one which strikes the water, and the refracted ray is the ray that is bent in the second medium, in this instance, the water.

The two angles which these rays form, with a line perpendicular to the surface of the water, separating in this instance the two media, the first between the incident ray and the line normal to the surface is the angle of incidence, and the other formed by the refracting ray and the perpendicular line as it extends into the water, the angle of refraction.

The second medium is more or less refracting than the first, according as the refracting ray approaches or deviates from the normal.

All the light which falls on the surface of a refracting substance does not pass into it completely; one part is reflected regularly or diffusely, while another penetrates into the medium.

In media which are uncrystallized, such as air, liquids, ordinary glass, the luminous ray is singly reflected; but in certain crystallized bodies, such as Iceland spar, selenite, etc., the incident ray gives rise to two refracted rays. This phenomenon is that of double refraction.

The following law prevails when a luminous ray is refracted from one medium into another of different refractive power.

I. Whatever the obliquity of the incident ray, the ratio which the sine of the incident angle bears to the sine of the angle of refraction is constant for the same media and the same colored light, but varies with different media.

If the light passes from a rare to a denser medium, the reflected ray approaches the perpendicular, otherwise it recedes from it. In order that refraction may take place, the incident ray must form an acute angle with the normal; if it form a right angle, it traverses the medium in a straight line. Rays impinging at right angles on the dividing surface of two transparent bodies are more refracted.

Index of Refraction.—By index of refraction is understood the ratio between the sines of the incident and refracted angles, sometimes spoken of as the refractive index, of the second medium with respect to the first.

The respective index varies with the media; for example, from air to water it is 4-3 and from air to glass it is 3-2. If the media are considered in an inverse order, that is, if light passes from water to air instead of air to water, or from glass to air, it follows the same course but in a contrary direction. Therefore, the refractive index is reversed; from water to air it is 3-4, and from glass to water 2-3.

The index of refraction of one medium to another on the undulatory theory of light is the ratio of velocity with which light travels in the second medium to that which it travels in the first. For example, the velocity of light in glass is 2-3, and in water 3-4 of its velocity in empty space. The refractive index depends on the rate of vibrational activity of the light corpuscles or its colors.

The refractive indices of the following substances are for D light and at a temperature of 20°.

Water	1.3333		
Alcohol	1.3616		
Carbon sulphide	1.6276		
a-bromnaphthalene	1.6582		
Ethyl cinnamate at 18.80	1.5607		
Common glass	1.515	—	1.615
Flint glass	1.614	—	1.762
Jena, heaviest silicate flint glass No. 557	1.9625		
Quartz, ordinary ray	1.5442		
Fluorspar	1.4339		
Air O° and 760 mm	1.0002922		

Plates with plane parallel surfaces cause the incident ray to be as much deflected toward the perpendicular as the issuing ray is bent from it; the two rays are, therefore, parallel to one another.

Lenses.—These are transparent media, which from the curvature of their surfaces have the property of causing the luminous rays which traverse them either to converge or diverge. They vary according to their curvature, and are either spherical, cylindrical, elliptical or parabolic. By a combination of their spherical surfaces either with each other or with plane surfaces, the number of different lenses is increased. Of these the double convex, plane convex and concave convex are all converging or convex lenses. They are thicker in the middle than at the edges. Concave lenses are thinner in the centre and thicker at the edges.

In lenses where the surfaces are spherical, the centres for these surfaces are called centres of curvature, and the right line which passes through these two centres is the principal axis. In or near every lens there is a point called the optical centre, which is situated on the axis, and which has the property that any luminous ray passing through it experiences an angular deviation; that is, the emergent ray is parallel to the incident ray.

Rays striking a concave lens parallel with the axis are dispersed after refraction. The axial rays passing through the centre of the lens are not refraction.

Objects viewed through a concave lens appear smaller and nearer.

The images formed by different forms of lenses do not concern us in this connection.

Refraction of Sun's Rays in a Double Convex Lens.—If the sun's rays be allowed to pass through a lens convex on both sides, they are refracted so as to converge as one point of light at a certain distance from the lens, dependent upon the focal length of the lens. If a piece of paper or wood be held at this converging point or focus, it will become heated and finally ignite. This is the principle of the

burning glass referred to under the physics of radiant heat. The convex lens acts, therefore, as a burning glass.

Refraction of Light Rays Parallel with the Axis by Convex Lenses.—When light rays impinge on a convex lens, parallel with the axis of the lens, they are so refracted that all of them pass through the focus.

Focal Rays in Relation to Convex Lenses.—When light rays have passed through a focus and then impinge upon a convex lens they become after refraction parallel with the axis of the lens. The axial rays pass through without refraction.

The Focal Length of a Lens and the Nature of the Refractive Index of its Material.—By focal distance is understood the distance of the focus from the centre of the lens.

Both of these factors enter into the construction of lenses to be used in connection with sources of light energy in therapeutic work. Both are determined mathematically. The transparency of quartz to the frequencies of the ultraviolet region is dependent upon the nature of its refraction.

The Effect of Lenses Dependent upon Their Diameter, Curve and Refractive Power of Their Substance.—The diameter and curve of lenses govern their effect as does also the refractive power of the substance from which they are cut. For example, glass or quartz.

Spherical Aberration and Chromatic Aberration.—When parallel rays strike a spherical lens close to the edge, they do not converge in one focus after reflection, but spread over a wider zone, whose axis is the focal line proper. The same is true of large spherical mirrors. To this phenomenon is given the name of spherical aberration. Its effect is to blur the image. It is especially prone to occur with thick lenses.

Lenses are also subject to chromatic aberration. As the term implies, they break up white light into its component parts, as does a prism. If a bundle of rays be thrown on a convex lens parallel to the optical axis, the violet rays which

are refracted at the sharper angles will intersect each other behind the lens at a shorter distance from it than the other rays, the longer, slower and less refrangible red will intersect at the greatest distance. At whatever point the image is caught but one color stands out distinctly, all the others are blurred.

Reflection and Refraction.—Both of these phenomena are of concern in the therapeutic uses of light. The impinging light is not reflected. A part finds its way into the second medium. This means that there is a certain loss of light. The amount of loss by reflection depends (1) on the nature of the media; (2) on the direction of the rays.

Refraction is seen in all its beauty in the diamond, in cut glass and in the prismatic pendants from cut glass.

Transformation of Refracted Light Energy.—All of the refracted light does not pass through the second medium. A part is used up in it and is converted into other forms of energy; for instance, heat, chemical energy, etc.

Reflected Light of Less Candle-power than Incident Light.—If the total strength of the light reflected by a body and that which passes through it be measured photometrically, it will be found to be less than that of the impinging light.

Prisms in Relation to the Decomposition of White Light.—If a beam of light pass through a prism it is diverted from its original direction and resolved into its component colors. There appear the colors of the spectrum, red, orange, yellow, green, blue, violet. These colors are not of sharp definition but merge insensibly into one another.

Dispersion.—Reflection not only changes the direction of a ray of light, but if it is not homogeneous, its nature is also modified; a ray of light is converted into a rainbow-colored band, as may easily be seen by the help of a prism. The many colored light rays are transmitted with uniform velocity in a vacuum, but in a denser medium the more rapidly vibrating violet rays undergo a greater retardation than the red rays which vibrate more slowly; the former,

therefore, are refracted more strongly than the latter. Passage through a second prism more strongly refracts the component rays but they are not decomposed any further; they are therefore simple and homogeneous and if combined by means of a lens white light is again produced.

Abnormal Dispersion.—As a rule the refractive index of a medium is greater the smaller the wave length of the particular light; in the visible spectrum the index steadily increases in passing from red to blue. There are substances which do not conform to this rule. Their solutions when employed as refracting and dispersing agents exhibit the inverse relationship between refractive index and dispersion. To this phenomenon is given the name of Abnormal Dispersion.

Luminous, Transparent, Translucent and Opaque Bodies.—Bodies are luminous when they emit light, the sun, and electric arc and incandescent solid or filament, for example.

Transparent Bodies. — Bodies which readily transmit light, as water, polished glass, gases permitting objects to be distinguished through them, are transparent or diaphanous.

Translucent Bodies. — Those bodies which permit the passage of light without the ability to distinguish objects are translucent. This is true of ground glass, oil paper, milk, blood, etc., and also of the more superficial parts of the living organism, such as the ear, hand, and even deeper tissues. This translucency of the living tissue, i.e., the blood to light, is availed of as an aid to diagnosis. Under all conditions it is due to the incorporation of foreign particles from which the light is diffusely reflected.

Opaque Bodies.—Bodies which do not transmit light, as wood, metals, are said to be opaque. Their opacity depends upon the thickness of their substance. No bodies can be said to be opaque, for if cut sufficiently thin, they are all more or less translucent. For example, the object glass of a telescope thinly silvered is so transparent that the sun may be viewed through it without danger to the eye, as the metallic surface reflects the greater part of the radiation which falls upon it. On the other hand, no body can be said

to be absolutely transparent. There would be no absorption in such a case.

Different media transmit different wave lengths. For example, glass which is transparent to light is not transparent to ultra-violet light.

Physical Condition of the Sun. — As an explanation of the occurrence of the dark lines in the solar spectrum, Kirchhoff concluded that the atmosphere of the sun encloses a luminous mass which emits a continuous spectrum of high illuminating power. This inner portion is either solid or liquid, and at a higher temperature than the atmosphere. Subsequent and more recent investigations, however, show that the sun is much more complex than Kirchhoff imagined. The nature of the *inner nucleus* of the sun can only be conjectured, as it is beyond the reach of observation. In all probability it consists of a gas at an extremely high temperature, and under such an enormous pressure that its properties must resemble to some extent those of a viscous substance, like putty. Surrounding this nucleus is the *photosphere,* composed of glowing cloud-like masses of vapor; it forms the visible surface and appears to correspond with the clouds in the terrestrial atmosphere. It is unknown whether it is separated from the nucleus by a definite surface. Externally, it is sharply but irregularly confined, being elevated in some places into *faculæ,* and in others depressed, forming *spots.* The *reversing layer* is situated directly over the photosphere and produces the Fraunhofer lines. Its thickness is only about 1,000 miles. The gases composing the reversing layer are not confined exclusively to the surface of the photosphere. They also occupy the spaces between the photospheric clouds and constitute the atmosphere in which these float. Above the reversing layer is the scarlet red chromosphere, consisting of uncondensed gases,—hydrogen and helium. Numerous prominences extend from this far beyond the surface of the sun. The exterior portion of the sun is termed the corona, it consists of clouds and irregular streams of light and

gradually merges into the surrounding darkness. The greater portion of the mass of the sun is within the photosphere, but the larger part of its volume is outside of it. The diameter of the solar atmosphere is at least double that of the central portion, and its volume consequently seven times as great as this. In the fact that the atmosphere of the nucleus of the sun is an atmosphere sufficient to volatilize metals, and also that the sun's mean density is low, there is found sufficient evidence for the belief that the nucleus of the sun consists of gas. As the temperature of the gaseous mass is far above its critical point, the high pressure must cause it to exceed water in density, and, therefore, the gases must be viscous and comparable in properties with molten glass or putty. The photosphere is undoubtedly a gaseous envelope, condensed in places into cloud-like masses of vapor in consequence of the heat radiating into space. These masses account for its irregular appearance, and the solid or liquid particles of them cause luminosity and produce a continuous spectrum, like the solid particles in an ordinary flame.

The spectrum of the sun spots exhibits a number of dark bands; the dark lines of calcium, iron, titanium, etc., are widened, the hydrogen lines are reversed, and the sodium lines are also frequently enormously widened and doubly reversed. These phenomena render it likely that the increased absorption is due to gases and vapors rushing in to fill a space and absorbing the light emitted from the cavity. Lines are sometimes displaced in consequence of violent motion of the gases. The faculæ show a reversal of the H and K bands of calcium, by a thin bright line running down the middle of each, and, whilst the reversal over a spot is generally "single" the bright line is usually "double" in the faculous region surrounding it. From this it is thought probable that the faculæ are not mere protrusions from the photosphere, but luminous masses of calcium vapor floating in the solar atmosphere and possibly identical with the prominences themselves.

The emission spectrum of the reversing layer, the cause of the Fraunhofer dark lines, can only be observed during a total eclipse; at the moment when the sun is completely obscured by the moon, the lines of the whole spectrum are seen to flash out brightly luminous.

The infrequent occurrence of this phenomenon commands the attention of the spectroscopist wherever he may be and astronomical expeditions journey to the ends of the earth to witness it.

This flashing spectrum was first seen by Young at the total eclipse of the sun in Spain on December 22, 1870. The moon had almost hidden the sun, the black lines were still visible, but at the exact moment when totality occurred, he saw the black lines disappear and "all at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with more numerous bright lines than one could count."[1]

The Chromosphere and its Prominences.—A spectroscope of high dispersive power, the slit widely open, permits a study of the spectra of the chromosphere and a view of the whole prominence if not too large. The prominences appear to bear a certain relationship to the sun's spots and faculæ; they are divided into two classes, quiescent, cloudlike, or hydrogen and helium prominences, and eruptive or metallic ones. The former resemble terrestrial clouds in appearance; the latter are highly luminous, but the degree of luminosity and the shape change with extreme rapidity. Their spectra are very complicated.

The Corona.—Much uncertainty prevails as to the nature of the corona. It is only visible during a total eclipse. The spectrum presents a double line in the green region 1,474 K. of wave lengths 5,316.87.

One of these lines is supposed to be due to iron as it coincides end to end with an absorption black line in the spectrum of the sun's surface far below. The other does

[1]Young.

not coincide with the line of any mode of matter yet found on earth. The substance is named coronium and awaits identification. The most plentiful gas in the corona is hydrogen. Calcium also is present, and thus far about 30 substances have been identified by means of their lines.

It is now generally admitted that the corona consists of an atmosphere extending 300,000 miles and of extreme tenacity.

It is as yet uncertain as to the true nature of the coronal streamers.[1] They are regarded as a permanent aurora, their position and direction being determined by the sun's magnetic field of force as the terrestrial field of force direct the beams of the aurora borealis; again they are believed to be due to light emitted and reflected from streams of matter ejected from the sun by forces acting in general, along lines normal to the surface of the sun, and most active near the centre of each sun-spot zone.

Radiant Heat.

Heat is not transmitted by the intervening air. For example, if one stands at a little distance from the fire or other source of heat a sensation of warmth is produced. This is not due to the temperature of the air, for if a screen be interposed the sensation immediately disappears. This would not be the case if the surrounding air had a high temperature. Just so the heat from the sun reaches us, that is it is transmitted to the body from the source of heat without affecting the temperature of the intervening medium. It is said, therefore, to be radiated. Take a hollow glass lens through which cold water is allowed to flow in a constant stream, and yet the solar rays concentrated by this arrangement will light a piece of wood placed in focus. Heat is also conducted as, for example, when the end of a metal bar is heated, a certain increase of temperature is presently observed along the bar. In this discussion of the subject,

[1]Landauer: Spectrum Analysis, pp. 203-207.

however, it is radiant heat which concerns us, the heat radiated from the sun or from a source of artificial light, the ordinary incandescent lamp, for example.

These bodies, therefore, send out rays capable of exciting the phenomena of heat, and these heat radiations (invisible light rays) penetrate the air without heating it, as rays of light through transparent bodies. The terms rays of heat, calorific rays or, as the author prefers, in discussing heat from radiant sources, thermal frequencies, are used in the same sense as ray of light, luminous rays, or visible light frequencies. Bodies of all temperatures have the power of radiating heat, nor is it necessary that they should be luminous as a fire or red hot ball. From bodies of sufficient temperature, heat radiations proceed which may be termed luminous, from others obscure heat. The brightly glowing anthracite fire emits luminous heat rays, the steam radiator obscure rays.

Measurement of Radiant Heat.—The presence of radiant heat may be readily detected by the use of Melloni's thermomultiplier, which is a thermopile, connected with a delicate galvanometer. With this apparatus Melloni was able to measure differences of temperature of 1/5000 of a degree. A more sensitive apparatus is that of C. V. Boy's radio-micrometer, which enables the detection of differences of temperature of 1/1000000 of a C.°

Radiation of heat is governed by the following laws:[1]

I. Radiation takes place in all directions from a body. It does not matter in what direction in relation to a heated body a thermometer be placed, a rise in temperature from every point is indicated.

II. In a homogeneous medium, radiation takes place in a right line. If a screen be placed in the right line which joins the source of heat and the thermometer, the latter is not affected. But in passing obliquely, however, from one medium into another, as from air into glass, the thermal rays

[1]Ganot's Physics, pp. 408, 409.

or frequencies are deviated the same as luminous rays or frequencies. This effect is known as refraction, and is fully considered under the head of refraction of light.

III. Radiant heat is propagated in vacuo as well as in air. Fix a thermometer in the bottom of a glass flask, so that its bulk occupies the centre of the flask. By the use of the blowpipe the neck of the flask is carefully narrowed, and by the air pump the interior is exhausted to a proper degree of vacuum and then sealed. If the apparatus then be immersed in hot water, or brought near hot charcoal, the mercury in the thermometer at once rises. As glass is a bad conductor, the heat rays could not travel so rapidly through the sides of the flask and the thermometer, therefore the increase of temperature must be by radiation through the vacuum. This phenomenon is daily seen in X ray tubes and vacuum tubes excited by electric sources.

Causes which Modify the Intensity of Radiant Heat.—There is understood by the intensity of radiant heat, at a particular place, the quantity of heat received on the unit of surface at that place. This intensity may be modified by (1) the temperature of the source of heat, (2) its distance, and (3) the obliquity of the calorific rays in reference to the surface which emits them. These modifications are regulated by the following laws:

I. The intensity of radiant heat is proportioned to the temperature of the source.

II. The intensity is inversely as the square of the distance from the source.

III. The intensity is less the greater the obliquity of the rays with respect to the radiating surface.

The first law is so self-evident as not to need demonstration, still if a metal box filled with water at 10°, 20° or 30° be placed successively at equal distances from a differential thermometer, the temperatures indicated by the latter (5) will be found to be in the same ratio as the box; for example, if the temperature of the thermometer corresponding to the

box at 10° indicates 2°, then that of the others will be 4° and 6° respectively.

The second law follows from the geometrical principle that the surface of a sphere increases as the square of its radius. Take a hollow sphere of any given radius, place a source of heat in the centre, each unit of surface in the interior receives a certain quantity of heat; now if the sphere of double the radius be used, a surface four times as great will be presented to the source of radiating heat; the internal surface will, therefore, contain four times as many units of surface, and as the quantity of heat emitted is the same, each unit of surface will receive one-fourth the amount.

The third modification is of less general applicability. The intensity is always less when the radiating rays are oblique to the radiating surface than where they are perpendicular. Expressed in mathematical formula, it is known as the law of the cosine; i.e., that the intensity of oblique rays is proportional to the cosine of the angle which these rays form with the normal to the surface. This law is not general, however; it has been known to be true only within narrow limits, i.e., with bodies which, like lampblack, are entirely destitute of reflecting power.

Mobile Equilibrium.—*The theory of exchanges suggested* by Prévost, of Geneva, in regard to radiant heat is now generally accepted. All bodies, whatever their temperature, constantly radiate heat in all directions. If two bodies of different temperatures be placed near one another, the one of higher temperature will experience a loss of heat through its emitting radiations greater than it receives; but the one of lower temperature will rise in temperature because it receives an energy of radiation higher than it emits. Both will ultimately come to have the same temperature, but there will still be an exchange of heat radiations between them. As the one does not receive under these physical conditions more than it emits, necessarily an equilibrium of temperature is reached.

This state is known as that of *mobile equilibrium of temperature.*

Reflection of Heat.—The thermal frequencies or rays which fall upon a body are, generally speaking, divided into two portions, one of which penetrates the body while the other rebounds or is repelled from the surface like an elastic ball. This part of the thermal activity is, therefore, reflected, and the reflection of heat rays, like those of light, is governed by the two following laws:

I. The angle of reflection is equal to the angle of incidence.

II. Both the incident and the reflected ray are in the same plane with the perpendicular to the reflecting surface.

The absolute reflecting power at an angle of 50° is for silver plate 97°, gold 95°, brass 93°, platinum 83°, steel 82°, zinc 81°, iron 77°, cast iron 74°. Therefore of the baser metals brass first, steel next and zinc third afford when polished the best reflecting surface for the lining of an incandescent cabinet for example, where the maximum thermal activity is required. Steel would seem to be the most practical substance from every point of view.

Reflection in a Vacuum.—Different conditions obtain in vacuo and in the air, the former being cooled or heated by radiation alone, the latter by contact with the air according as it is cooler or hotter than the radiating body. The quantity of heat gained or lost in a second is governed by the temperature; it is greater according as the difference of temperature is greater.

Burning Mirrors.—From the high temperature produced in the foci of concave mirrors, they have been called burning mirrors. It is stated that Archimedes burnt the Roman vessels before Syracuse by means of such mirrors. Buffon constructed burning mirrors of such power as to prove that the feat attributed to Archimedes was not impossible. The mirrors were made up of silver plane mirrors about 8 inches

long by 5 inches broad. They could be turned independently of each other in such a manner that the rays reflected from each coincided at the same point. With 128 mirrors and a hot summer's sun Buffon ignited a plank of tarred wood at a distance of 70 feet. The concavity of the Mangin mirror at the back of the marine searchlight accounts for the extreme heat of the beam of light proceeding from it, a temperature much beyond that of arcs of the same ampèrage when not so reflected. The power of throwing off a greater or less proportion of its incident heat, is known as its *reflecting power,* and it varies with different substances. Of the metals, and also other substances, taking brass as the unit at 100, their relative reflecting power is as follows:

Polished brass	100
Silver	90
Steel	70
Lead	60
Indian ink	13
Glass	10
Oiled glass	5
Lampblack	0

But their absolute reflecting power is the relation of the quantity of heat reflected to the quantity of heat received.

The Absorption of Heat.—Heat, in common with light, is *absorbed,* and the *absorbing power* of a body is its power which permits a greater or less quantity of the heat which falls upon it to pass into its mass. The absolute value of the absorbing power is the ratio of the quantity of heat absorbed to the quantity of heat received. The absorbing power of a body is always inversely as its reflecting surface: a body which is a good absorbent is a bad reflector, and *vice versa.* The sum of the reflected and absorbed heat is always less than the incident heat. The latter is divided into three parts: (1) one which is absorbed, (2) another which is reflected regularly according to the laws for reflection of heat, and (3) which is irregularly reflected in all directions, and which is called *scattered* or *diffused* heat. A part of the heat may also pass through a substance as light passes through glass. Various

substances possess varying powers of heat absorption. The radiating or emissive power of a body is its capability of emitting at the same temperature, and with the same extent of surface, greater or less quantities of heat.

From experimental data the identity of the absorbing and radiating power has been determined.

As they are equal, any cause which affects the one will affect the other as well. Whatever increases the reflecting power diminishes the radiating and absorbing power, and *vice versa.* These different powers vary with different bodies and even in the same bodies, they are modified, for example, by the degree of polish in metals. They are also modified by the density, the thickness of the radiating substance, the obliquity of the incident reflected rays, and lastly, by the manner of the source of heat. Metals have the greatest reflecting power, lampblack the least.[1]

Vibration of the Particles of a Heated Body.—A heated body is to be regarded as one whose particles are in a state of vibration, and the higher the temperature of the body, the more rapid are these vibrations. A diminution in temperature is but a diminution in the rapidity of vibration of the particles. The propagation of heat through a bar is due to a gradual communication of the vibratory motion from the heated part to the rest of the bar. The propagation of this motion of heat vibrations even through the best conductors is comparatively slow. There is a difference in different substances, some transmitting the vibratory motion from particle to particle much more rapidly than others. When a screen is removed from before a fire or the clouds drift away from the face of the sun, the sensation of heat is instantly perceived. Here the heat radiations pass from the one body to the other without affecting the temperature of the space through which it passes. The particles of a heated body being in a state of intensely rapid vibration communicate their motion to the

[1]Ganot's Physics, sec. 431, p. 419.

ether around them, the particles of which are set in successive vibration and hence give rise to waves in the ether which travel through space and pass from one body to another with the velocity of light. A ray of heat is merely a series of waves moving in a certain direction. In heated bodies, definite wave lengths are emitted according to its temperature. In other words, its particles vibrate in a certain period. The higher the temperature, the shorter the wave lengths and the more frequent because of the more rapid vibrations, but they coexist, however, with all those previously emitted by the same body. The motion is therefore at each successive temperature a compound of all preceding ones. The carbon filament of an incandescent lamp at a certain temperature, dependent upon the E. M. F. and R. of the current used, becomes dull red. i.e., its particles vibrate at a definite period and there is an emission of slow waves of long length. Bring it to a brighter glow and there are shorter and more frequent waves, while brought to full incandescence means still more rapid vibrational activity of the carbon filament under excitation by the electric current, and therefore waves still shorter and more frequent, but this latter vibrational activity gives not only the shorter and more frequent but all the wave lengths which have preceded it. It is a complex of the whole. So is the radiant energy of the sun and of the electric arc a complex of all the rates of vibrational activity from the lowest to the highest. The optic nerve is insensible to a large number of the wave lengths thus produced, apprehending only those that form the visible spectrum. Though intense motion may pass through the humors of the eye, yet if the undulations of these oscillating corpuscles be lower than the red or higher than the violet yet we shall be entirely unconscious of the fact, for the optic nerve cannot take up and respond to the vibrations which exist beyond the ends of the visible spectrum, either below the red or above the violet. These latter are invisible or obscure rays.

Some flames, that of a Bunsen burner or an oxy-hydrogen flame, emit vast quantities of obscure rays, for their

vibrations though capable in part of penetrating the media of the eye are incapable of exciting the sensation of light in the optic nerve.

Thermal Analysis of Sunlight.

The sun as a source of radiant heat concerns us first and therefore a thermal analysis of sunlight is called for.

Let a narrow vertical slit be made in the shutter of a dark room and strongly illumined by sunlight and let the light from the slit be focused by a rock-salt lens on a screen and a rock-salt prism suitably placed. The light as it emerges from the prism will be found to present on the screen a band of colors in the following order: red, orange, yellow, green, blue and violet. This constitutes the spectrum, which is more extensively considered under the discussion of light. By placing a narrow delicate thermopile on the space occupied by each of these colors, it will be found to be very little affected on the violet, but a gradual rise of temperature will be noted as it passes over the other colors. Unconsciously and without any knowledge of this physical fact, on the part of the observer, blue and green are spoken of as cold colors, while red and orange are universally recognized as warm tones. If the pile be moved beyond the limits of the luminous or visible spectrum the temperature will gradually rise to a given point where the maximum is obtained. From that to another given point the pile indicates a decrease in temperature. At that point it ceases to be affected. The first point is as far from the second as the second from the third; that is, there is a region in which thermal effects are produced extending considerably beyond the red end of the spectrum. These rays or frequencies represent the different rates of vibration or swing of the oscillating corpuscles. In their passage through the prism, they are unequally broken or refracted; those of the longest wave length or slowest vibrating period are least bent aside, i.e., they are the least refrangible, while the rays of shortest

wave length, most rapid vibrating period, are the most refrangible. In the radiant energy of the sun there is a vast assemblage of superposed waves of different wave lengths. The prism breaks the compound waves into their constituents, the short waves being more refrangible than the long ones. All save the red frequencies and those below will be considered under the visible spectrum. The evidence of the existence of the rays beyond the violet is obtained by their action on silver salts, on fluorescent substances, etc. But it matters not what the radiation or wave length, if it falls on a lampblack surface, it is absorbed by it and converted into heat, the absorption thus measuring the energy of the incident radiation. The energy measured in this way is greatest at the red end of the spectrum and beyond, hence the use of the term heat rays or thermal frequencies, while in contradistinction, the visible frequencies are called the light rays or luminous frequencies, while those beyond the violet are spoken of as the actinic rays. There is but one kind of energy radiated from the sun, the heat, light or chemical effects depend entirely upon the state or condition of the matter upon which the different wave lengths may happen to fall. Langley,[1] to whom photo-physics is indebted for elaborate researches into the previously unknown radiations, especially at the infra-red end of the visible spectrum, states that "up to 1872 it was almost universally believed that there were three different kinds of entities, active, luminous and thermal, represented in the spectrum. There is one radiant energy which appears to us as 'actinic,' 'luminous' or 'thermal' radiation according to the way we observe it. Heat and light then, are not things in themselves, but different sensations in our own bodies, or different effects in other bodies; are merely effects of this mysterious thing we call radiant energy." Over sixty years ago Melloni, an Italian physicist, wrote, "Light is merely a series of calorific indications, sensible to the organs of sight, or *vice versa,* the radiations of obscure heat are veritable invisible radiations of light." This theory was not adopted until the physical fact had been demonstrated by the researches of Langley which were much more refined and complex than those of other investigators. There is but one radiant energy to the modern physicist as unquestionably it will be agreed that there is only one matter.

[1]Proceedings American Association Science, Cleveland Session.

Chemical action is not confined to frequencies of short wave length, any more than thermal action is confined to the frequencies of the red region. Under proper conditions the green, red and infra-red frequencies will all produce photographic action. A proof of the chemical action of the red frequencies can be had in the ability to photograph through the human body. At least the inference seems fair, for it is the red frequencies which pass through. The hand photographed by Gebhard had a photographic plate placed in the hollow of the palm. It was then imbedded in plaster of Paris save for the dorsal surface. After 20 minutes' exposure to the light of an electric arc, the plate was subsequently removed to the dark room and developed. It was found to be darkened and the contours of the hand and fingers were distinctly seen, showing that the light had penetrated. Similar experiments have been made by Freund, Strebel, Kime, Gottheil and others. The only physical distinction to be made between light rays, heat rays, and actinic rays is that of wave length. And by reason of the different wave lengths a difference of physical action upon the living organism takes place; it is with different component parts of the structure as it is elsewhere in the physical world, the effects are those of heat, light, or chemical action according to the state or condition of matter upon which the energy from the sun or an artificial source is radiated.

Radiation does not leave the sun either as light or heat but as radiant energy. The wave lengths of the radiation lying within certain limits fall upon the eye and they are called light; the same wave lengths will decompose the silver bromide of a photographic plate and hence they are called

actinic rays; while equally well will they raise the temperature of a blackened bulb thermometer, therefore they are heat rays. The short and high frequencies of the vibrational activity of the oscillating light corpuscles are the best adapted to produce chemical action, which is the highest form of vibrational activity.

As prisms of different materials absorb rays of different refrangibility to unequal extents, the maximum heat will be found to vary according to the material used. With the rock salt we have found it to be in the red, with a prism of water it is in the yellow, while with one of crown glass it is in the middle of the red. Rock salt however practically permits the passage of all the frequencies, even the ultra-violet and gives therefore a very normal spectrum. Tyndall showed by his experiments that the heating effects gradually increased from the violet but were greatest in the dark space beyond the red; the position being about as far from the visible red as the latter was from the green, and the total extent of the invisible spectrum was found to be twice that of the visible. The visible part of the sun's radiance is only a small fraction of the output.

Langley, to whom we are indebted for the longest wave length, devised a very sensitive instrument known as a bolometer,[1] or actinic balance, by means of which he explored farther and farther into the long heat wave region, using prisms of rock salt, because this substance permits the passage of more heat than any other known. Professor Langley's new bolometer is the most sensitive instrument ever constructed. In the Smithsonian report of 1900, appears a plate showing the long infra-red or new spectrum, which is thirteen times the length of the spectrum which makes impress upon the eye. In it are to be seen wide dark bands as in the visible spectrum. They indicate absorption of course, as absorption is the cause of all dark and cold spaces in the solar spectrum, but it is not known what modes of matter caused them.

[1]For description see Ganot's Physics, sec. 932, 16th edition.

In the thermal end of the spectrum are waves of varying intensities, showing that the energy of the sun is uneven in its distribution. Langley's bolometer detects the lines and bands of this end of the spectrum by means of their temperature. Cold in the bolometer spectrum has the same significance as darkness in the visible spectrum and these dark lines vary greatly in width—just as do those of the visible spectrum. These long slow waves are difficult of recording graphically, and are not even comparable in this respect with the waves constantly issuing from radium, by means of which a much stronger impression is made upon a sensitive plate. But as has been shown heat is not confined to this region as the frequencies of the visible spectrum also give off a great deal of heat, therefore the quantity of light is extremely small, and the investigator in his attempt to devise a means for artificial illumination deficient in heat is, after all, seeking that which nature has not provided in the radiant energy of the sun.

Langley used in his investigations of the heat end of the spectrum a Rowland grating[1] so as to avoid effects due to the absorption and measured the heat by means of his bolometer which showed differences in temperature of 0.00001° F. According to Ganot there was obtained in this way an invisible spectrum extending beyond the red to 20 times the length of the visible spectrum. The absorption of the radiation by the bolometer begins to be measured just outside the violet at a wave length of about 0.25μ and is at a maximum at a wave length of 0.65μ. The depressions shown in the curve represent the dark lines or what is known as Fraunhofer's lines.[2]

If a solar spectrum could be produced outside the atmosphere it would probably give a spectrum more like that of the electric light, which is unaffected by the atmospheric absorption. Flint-glass prisms and especially water will absorb the infra or called sometimes the ultra-red radiations.

[1]See description, Ganot's Physics, sec. 662.

[2]Original paper, Phil. Mag. (V.) Vol. 26, p. 505.

The absorption in the atmosphere has always been attributed to the aqueous vapor, but according to Cornu[1] it is absorbed by the oxygen and nitrogen of the air.

The thermal frequencies from bodies heated under incandescence are all absorbed when the beam is passed through a solution of alum in water. Rock salt permits the passage of both the luminous and the obscure radiation. A solution of iodine in carbon bisulphide, which Tyndall found to be impervious to the brightest light, is very pervious to radiation of great wave length, only a slight absorption being affected by the bisulphide. This means was used in determining the relative proportion of luminous and obscure radiations under different conditions, which were found to be as follows:

Source.	Luminous.	Obscure.
Red hot spiral	0	100
Hydrogen flame	0	100
Oil flame	3	97
Gas flame	4	96
White hot spiral	4.6	95.4
Electric light	10	90

In medical work, the same agents are useful in cutting down the obscure radiations or thermal frequencies. A solution of alum in water is used for this purpose. Rock salt, which permits the passage of the ultra-violet frequencies, permits the passage of all the thermal frequencies and is therefore not so good as quartz in practical work, still by having a number of pieces and changing from a warm to a cool one, the end can be obtained.

In India it is the custom to paint goitres with red iodide of mercury and then expose the part to the action of sunlight. Doubtless this is done because of the fact that iodine absorbs all save radiation of great wave length. It is a great absorber of light. In the author's experience, a case of goitre was so treated by request of the patient, who had

[1]Landauer: Spectrum Analysis.

read largely but not always wisely. A few exposures resulted in a very severe dermatitis, infinitely more so than had followed the use of the same light source alone. Although told it would follow upon the treatment, the patient discontinued treatment upon its appearance and the ultimate outcome in relation to the goitre is not known

Calorescence.—As Stokes converted the rays of high refrangibility (see Fluorescence, Chapter XX.) into those of lower refrangibility and invisibility, so Tyndall increased the refrangibility of the infra or ultra-red frequencies, rendering them visible. This was done by placing the charcoal points of an electric-light filament in front of a concave silvered glass mirror, concentrating the rays to a focus about 6 inches distant. A cell full of a solution of iodine in carbon bisulphide, which has the power of stopping all luminous frequencies, but gives free passage to the non-luminous frequencies, was placed in the path of the beam, and a piece of platinum was then placed in the focus of the beam thus sifted and raised to incandescence by the invisible frequencies. In the same manner, charcoal in vacuo was heated to redness. Under a proper arrangement of the charcoal points a metal may be raised to whiteness, and the light emitted from it on prismatic analysis will yield a brilliant luminous spectrum. This luminous spectrum is derived entirely from the invisible infra-red spectrum, and to this transmutation of the non-luminous frequencies into the luminous frequencies Tyndall gave the name of *calorescence.*

Tyndall still further showed in these experiments that by placing the eye in the focus, guarded by a small hole pierced in a metal screen, in order that the converged rays should only enter the pupil, and not affect the surrounding part of the eye, no sensation of light was produced, nor was there scarcely any sensation of heat. A powerful beam undoubtedly reached the retina, although a considerable portion was absorbed by the humors of the eye, for under separate experiment Tyndall showed that about 18

per cent. of obscure radiation from the electric light passed through the humors of an ox's eye. The visual tract, i.e., the optic nerve and the brain, does not seem to be able to take cognizance of or respond to frequencies below the red either as light or heat.

Diathermancy and Athermancy—Transmission of Thermal Rays.—Diathermancy is the term used to express the power which bodies have of transmitting heat, and bears the same relation to radiant heat that transparency does to light. Athermancy, on the other hand, is the term used to express the power of stopping radiant heat and corresponds to opacity for light.

A diathermanous substance is one which allows incident radiation to pass through it, apart from any consideration of the wave length of the radiation. A transparent substance transmits waves of medium length, and may or may not be opaque to the very long or very short waves. A substance may be absolutely opaque and yet permit the ultra-violet or the infra-red or both to pass. By heat rays it is the infra-red which are generally understood.

By his experiments Melloni found that calling the total radiation 100 there was transmitted as follows:

Carbon bisulphide	transmitted	63
Olive oil	"	30
Ether	"	21
Sulphuric acid	"	17
Alcohol	"	15
Solution of alum or sugar	"	12
Distilled water	"	11

With solids when cut into plates 0.1 inch thick it was found that out of every 100 rays

Rock salt	transmitted	92
Smoky quartz	"	67
Transparent lead carbonate	"	52
Selenite	"	20
Alum	"	12
Copper sulphate	"	0

A practical application of these tables is to be found in the small quantity of thermal frequencies transmitted through distilled water, hence the reason for using it preferably for the water-cooling cylinders of tubes with condensing lenses, as in the Finsen tube; and in the complete athermancy of copper sulphate the reason for its use as a filter when the solar energy is used for treating skin lesions.

Tyndall in a series of experiments made to show whether there was any relation between diathermancy and transparency proved that a layer of water 0.2 of an inch thick absorbs 80.7 per cent. of heat from a red hot spiral, and transmits 19.3 per cent., and that there was no such relation.

Influence of the Thickness and Nature of Screens.—Rock salt transmits all kinds of heat, i.e., from different sources, with equal facility, and is the only substance to do so. Its analogy may be found in white glass which is transparent to white light, no matter what its source. With most bodies absorption of heat increases with the thickness, although by no means in direct proportion. Rock salt is an exception to this rule. The absorption takes place in the first layers; the rays which have passed these possess the property of passing through other layers in a higher degree, so that beyond the first layers the heat transmitted approaches a certain constant value.

Bodies which transmit heat of any kind readily are not heated. For example, a window pane is not much heated by the strongest sun's heat; but a glass screen placed before a fire stops most of the heat and becomes heated itself thereby. So the blue glass screen used in connection with the marine searchlight mechanism: The patient exposed to the action of the blue frequencies suffers no heat, it is not transmitted, but the glass of the screen itself becomes very hot, sometimes cracking.

Absorption by Luminous Heat.—From his experiments Franklin found nearly a century ago that the absorption of heat by colored clothes increased with the darkness of the color. But he used a luminous source of heat, therefore,

his conclusions only hold good for luminous heat. With obscure heat, all clothes were equally absorbent.

The thermal frequencies or heat rays are susceptible of double polarization and refraction.

Dry air, oxygen, nitrogen and hydrogen are but little absorbent of radiant heat, their presence being but little different from a vacuum.

Assuming the absorption of dry air to be 1, carbonic acid, for example, under the same pressure, 30 inches, is 90.

The absorption of heat by gases varies with the pressure. Tyndall, in his experiments on the behavior of aqueous vapor to radiant heat, showed that on a day of average humidity the absorption due to the transparent aqueous vapor present in the atmosphere is 72 times as great as that of the air itself, though in quantity the latter is about 200 times greater than the former. He also showed that with the sun at heights which are virtually equal there is the smallest transmission of heat on those days on which the pressure of aqueous vapor is greatest; that is, when there is most moisture in the atmosphere. In this physical fact is to be found a reason for constructing incandescent light baths in such a manner as to prevent, if possible, great moisture of the air of the cabinet from the sudatory action established.

Perfumes are great absorbers of heat. Tyndall found that elementary gases were the feeblest absorbents, while gases of complex constitution were the most powerful. Thus it may be inferred that absorption is mainly dependent upon chemical constitution. Absorption and radiation are, therefore, molecular acts independent of the physical conditions of the body.

The properties which bodies possess of absorbing, emitting and reflecting heat meet with numerous applications in the domestic economies and arts.

Applications.—As a rule white bodies reflect heat very well, and absorb very little, but the contrary is true of black bodies. An exception is to be found in white lead, which has as great absorbing power for non-luminous rays as lampblack. Dark cloth, cotton, wool and other organic substances when exposed to the action of radiation from luminous sources are powerful absorbents. White clothing is cooler for summer wear because it reflects by reason of the absence of color rather than absorbs the thermal frequencies of the solar rays. It permits the transmission of the chemical rays. Therefore in the tropics where the chemical intensity of sunlight is very great, red and yellow are worn underneath while white is used for outer wear. Polished surfaces emit heat more slowly than dull surfaces.

The upper regions of the atmosphere are cold, notwithstanding that they are traversed by intense heat because of the diathermancy of dry atmospheric air. The intense heat on the top of mountains is undoubtedly due to the comparative absence of aqueous vapor at these elevations.

The use of glass for shade in gardens to protect plants depends partly on the diathermancy of glass for heat from luminous rays, and its athermancy for obscure rays. The heat from the sun is largely of the former quality, but by contact with the earth it is changed into obscure heat, which cannot traverse the glass. A considerable part of the solar energy is transmitted by water, and bottles of water may act as lenses. Accidents might happen in this way, gunpowder, for example, be fired while a drop of water on leaves in greenhouses might act in the same manner, and to the destruction of the leaves. Rock salt coated with lampblack or still better with iodine transmits heat, that is, the infrared rays but completely stops luminous heat. Alum either as a plate or in solution, or a thin layer of water is permeable to light, but stops all the heat from obscure sources.

This property is made use of in apparatus illuminated by the sun's rays, in order to sift the rays of their heating power. If desired to avoid too intense heat from an electric light thus used a vessel of water or solution of alum is used.

For example, a Finsen tube on the one hand and a sun lens on the other.

The different sources of heat generally are (1) mechanical sources, comprising friction, percussion and pressure; (2) the physical sources, solar radiation, terrestrial heat, molecular action, change of conditions, and electricity; (3) the chemical sources or chemical combinations, and more especially combustion.

Radiant heat as it concerns us here originates from (1) the sun, and (2) from incandescent lamps. There is no source of heat so intense as that of the sun.

Attraction and Repulsion Arising from Radiation.—Crookes discovered a very remarkable class of phenomena which are due to the radiant action of heated and luminous bodies. It beautifully illustrates the attraction and repulsion arising from radiation (1) of radiant heat, (2) light visible and invisible, (3) cathode rays. A description of it is incorporated in this chapter.

Crookes' radiometer[1] is a device consisting of a lightly poised structure, similar to a windmill, weighing not more than two grains, secured in a glass bulb from which the air has been mostly exhausted, so as to leave a fairly perfect vacuum and which is fused at its proximal end into a glass tube, and this in turn is secured to a base of wood which serves as a support. The vane or fly, as it is called, is composed of tiny discs of mica fastened to four fine aluminum wires. These are secured in the centre of the vacuum tube or bulb to a fine steel point which is fused into the distal end of the bulb. The one side of the mica disc is covered with lampblack. When exposed to the action of light or heat, a candle, for example, brought near the fly, the fly is attracted and rotates slowly in a direction showing that the blackened side moves toward the light. This movement, which indicates an attraction, depends upon a certain state of rarefaction. The speed of the rotation of the fly gradually

[1]Ganot's Physics.

diminishes in rapidity as the air within the vacuum is still further rarefied until a certain point is reached when the fly ceases to rotate. Let the rarefaction be pushed beyond the point at which the rotation of attraction ceases and the reverse of the phenomenon takes place, viz., repulsion, and the blackened vanes move away from the source of light or heat. In a double radiometer, in which two flies are pivoted independently one over the other, having their blackened sides opposite each other, the flies will rotate in opposite directions on the approach of a lighted candle. The rotations are reversed when a cold body is brought near instead of a hot one. The experiments of Crookes and Kundt brought to light the very important fact that what had been regarded as a complete vacuum, was not in reality and the existence of a gaseous residue must be taken into account. The phenomena are not specially influenced by the nature of the gas, for whether the vacuum be one of hydrogen, or aqueous vapor, or of iodine vapor there is no material difference in the result, save that with hydrogen the exhaustion need not be pushed so far as with air. The repulsion takes place with all the rays of the spectrum, the intensity diminishing from the ultra or infra-red to the ultra-violet. The interposition of a plate of alum, when the chemical frequencies, violet and ultra-violet, are active, has no effect upon the phenomena, but a solution of iodine in carbon bisulphide diminishes the repulsion. The rapidity of rotation depends upon the intensity of the source of light. A strong light causes so rapid a rotation as to prevent determination of the rate of speed. Two candles, for example, placed at the same distance will secure double the speed of one. When two different sources of light are placed successively at the same distance, and produce the same rate of rotation, then their intensity is equal. If when placed at different distances they produce the same speed of rotation, their intensities are directly as the squares of these densities from the radiometer. This is the principle which governs the use of the instrument as a photometer, for comparing and measuring different sources

of light. Comparative measurements of the intensity of light may also be made by a Crookes radiometer, and the distribution of energy in the solar spectrum investigated by its means.

When the pressure has not been reduced beyond a certain point, i.e., as long as the apparatus still contains air, it is not difficult to explain the phenomena of attraction observed in the experiments by the action of convection currents.[1]

Heat falling upon the blackened disc will raise its temperature, and the temperature of a layer of air in immediate contact with the disc, would also be raised. This would cause it to expand and rise, flowing over the space behind the disc, thereby increasing the pressure there. The repulsion observed, however, at a higher degree of vacuum is due to a reaction behind the vane and the glass envelope, and is at once an illustration and a proof of the modern views as to the constitution of gases. The general nature of this theory is that gas is an assemblage of independent molecules, which are perfectly elastic, and which move with great rapidity; the pressure is caused by their impact against the side of the vessels in which the gas is contained. The equal transmission of pressure in gases is effected by the impact of the molecules against each other. The mechanical effect of the force of repulsion is calculated by Crookes to be equal to about the 1/100 of a milligramme on a square centimetre. This force is sufficient to account for the effects observed by reference to admitted principles of the mechanical theory of gases (Stoney). The light vibrations pass through the thin glass, without raising its temperature, and falling on the blackened side of the vane is absorbed by it. In consequence thereof it becomes slightly hotter. The layer of extremely rarefied air in its immediate contact with the blackened disc will also become somewhat hotter, and the molecules will fly from the disc with greater velocity. These more rapid motions would be equalized by their impacts

[1]For Convection Currents, see pp. 404, 414, Ganot Physics, 16th edition.

against other molecules and a uniformity of pressure, i.e., of temperature would be established under ordinary pressures or even at moderate degrees of rarefaction. With the increase of rarefaction, however, the frequency of these intermolecular shocks diminishes rapidly and in consequence a great number of the molecules, after having been heated by contact with the blackened sides of the palette, will strike against the cold glass. The effect of this will be to cool these molecules, that is, to diminish their velocity, and it will be this kind of molecules chiefly which will fall on the back of the disc and on the regions behind it. An excess of force equal and opposite to that on the glass acts against the front of the disc and accounts for the phenomenon exhibited by Crookes. Therefore, other things being equal a fly will rotate more rapidly in a small than a large bulb.

Spectrum Analysis.—Spectrum analysis is a chemico-analytical method by means of which it is possible to determine the constituents of a substance by observing the refraction (dispersion) or the diffraction of light rays.[1] It also offers an opportunity of investigating the molecular structure of matter. When light rays are refracted the image produced is termed a spectrum. Rays of all refrangibility are emitted by white hot bodies and form what is termed a *continuous spectrum,* Plate 1. On the other hand, glowing gases of vapors emit rays of definite refrangibility. The spectrum of these is a *discontinuous* one consisting of bright lines which are characteristic of each substance. These characteristic lines serve for the identification of given substances whether they exist singly or in connection with other bodies. In this way the constituents of the sun are known, as the solar spectrum with its many colors and shades of coloring is the written or pictured evidence of the nature of its molten matter.

In the passage of rays from a white hot solid through a colored medium, some of them are retained and give an

[1]Ganot's Physics, 16th edition.

absorption spectrum. This varies with the chemical composition of the medium. By reason of the extreme delicacy characteristic of spectra reactions, their employment has led to the discovery of a number of new elements which occur in small quantities only. The distance from the source of light has little effect on the spectrum, therefore, it is successfully employed for the investigation of celestial bodies. extending a knowledge of them not dreamed of and unattainable in any other way.

In common with all scientific development, the history of spectrum analysis is one of exceeding interest, and both for an epitomized historic sketch as well as complete spectrum analysis, the reader is referred to Landauer's work,[1] and also Watts' Index of Spectra.[2] Spectrum analysis was founded by Kirchhoff and Bunsen in 1859.

Spectra are obtained by means of (1) prisms and (2) by means of gratings. There are two kinds of gratings made, the one of glass, which is transparent, and the other of speculum metal. The latter is the one most commonly used in spectroscopic work as it absorbs less light than the glass. The most complete gratings are Rowland's. His plane and concave gratings with from 10,000, 14,438 and 20,000 lines per inch are almost faultless and comparatively free from scratches caused by irregularity of the diamond point.

Diffraction.—The production of spectra by means of gratings is due to diffraction; part of the light traversing the spaces between the rulings continues in a straight line, but a portion is bent sideways or refracted by the edges of the opaque parts.

The wave theory of light permits of the following explanation of this phenomenon: The light waves which fall on a fine slit cause the particles of ether present to vibrate; this motion is communicated to the neighboring particles and produces an equal number of light waves, which reinforce, weaken or neutralize each other, in accordance with the law

[1] Spectrum Analysis. John Landauer.
[2] Watts' Index of Spectra.

of interference. This neutralization occurs in all directions, in which the difference between the two sets of waves is other than a whole wave length. The image of the slit in the middle in white light diffracted by a grating is white, because at this point all the colors are superposed, but the color waves which differ by one wave length collect at each side according to their wave lengths, and form a spectrum of the first order; these rays with a greater difference of phase forming the spectra of the second, third . . . . mth order.

When the distance between the lines of the grating is known the wave lengths are determined by measuring the angle of diffraction with a gonimetre.

In this way the following values in ten millionths of a millimetre for the Fraunhofer lines of the spectrum were obtained. (See colored plate.)

The wave lengths are given in Ångstroms:

A	7954.06	
B	6876.46	
C	6563.06	
D_1	5896.15	
D_2	5890.18	Sodium Lines.
E_1	5270.50	
E_2	5269.72	
F	4861.49	
G	4308.	
H_1	4101.85	
H_2	3968.62	

The wave length λ (1) is determined by dividing the velocity (v) (2) by the frequency. The wave length of the extremity of the visible red found at the lower end of the spectrum, is for the A-line .000076, that of the yellow D-line .0000589, and that of the K-line at the limit of the visible violet, .000039 mm. The velocity of light is known to be about 300,000 kilometres per second.

Given the velocity and the frequency, the number of the vibrations (n) can be obtained by the formula $n = \frac{v}{\lambda}$.

These are two common units of wave lengths smaller than the millimetre. By reason of the magnitude of the figures when the millimetre is used, it is much more simple to use the unit adopted for the measurement of wave length in a vacuum, the millionth part of a millimetre—0.001 micron. This unit is represented by the symbol $\mu\mu$. One-tenth part of this, equivalent to 1/10000000 of a millimetre, is known as Ångstrom's unit. As visible radiation is from .000077 to .000039 millimetre, its equivalent in microns is from 0.77 to 0.39 micron or 7,700 to 3,900 Å. or Ångstroms.[1]

These numbers are inconceivably great, therefore it is usual to define the color by the wave length, although this varies with the medium.

Listing's scale is used for the classification of lines of the spectrum, according to color; it runs as follows:

.... to 7230 infra-red. 5850 to 5750 yellow.
4540 to 4240 indigo.
7230 " 6470 red. 5750 to 4920 green.
4240 to 3970 violet.
6470 " 5850 orange. 5920 to 4550 blue.
3970 to .... ultra-violet.

The most readily recognized lines in the spectrum are from A to H. The eye is most sensitive to the light between D and E, that is, a part of the yellow. The light becomes less and less visible from that point toward either end, until the red rays beyond A and the ultra-violet beyond H are hardly distinguishable.

The solar spectrum is crossed by thousands of black lines known as Fraunhofer's lines, from the name of the discoverer, scattered here and there in the midst of the brilliant and gorgeous colors of the spectrum. Every phase of matter known casts lines in the spectrum which are bright and highly colored, not black. Or in other words each phase of matter, when corpuscles are torn apart and separated widely enough to allow them to oscillate, vibrates at

[1] Landauer: Spectrum Analysis, pp. 11, 12.

its own definite rate. The oscillation of each corpuscle will cause another to swing, and another, the motion being in a wave movement. But each wave strikes its own place in the spectrum and the bright lines in the spectrum are formed by sets of the similar waves, due entirely to their wave length and rates of oscillation. These appear in the solar spectrum as a result of the intense heat acting upon the different substances of which the sun is composed. Artificially, there is to be had in the electric arc a similar source of energy, and by placing in the crater of the positive carbon different substances for volatilization, or forming the electrodes of them as with carbon, they are torn apart by the intense heat and their corpuscles are made to swing at their own rate. The instant the gas becomes hotter than white is the instant when each corpuscle is torn away from all the others, to vibrate at its own rate. And as the corpuscles swing or oscillate one after another to form a wave they take a definite place in the spectrum, easily determined by means of a spectroscope.

They may each one be regarded as a letter in nature's alphabet. Their positions are measured with accuracy, and waves sent from iron, oxygen, sodium, titanium, helium, potassium, no matter what the substance, fall absolutely into their own and a definite place in the spectrum.

The Visible Spectrum.—Only the small portion of the spectrum between wave lengths 400$\mu\mu$, and 760$\mu\mu$ is, in ordinary circumstances, visible to the eye, but the part beyond 800$\mu\mu$ becomes visible if the shorter waves are cut off, by means of a dark red glass, whilst those far beyond the 400$\mu\mu$ are seen if the longer waves are eliminated.

The Invisible Spectrum.—The region beyond 760$\mu\mu$ is termed the infra-red, while that below 400$\mu\mu$ forms the ultra-violet. In the former Langley reached a wave length of 5300$\mu\mu$ and Rubens one of 575$\mu\mu$.

The infra-red rays may be detected by their thermal and photo-chemical properties and also by means of phosphorescence. See page 76. For the investigation of this region

Langley's actinic balance or bolometer is employed; by its means a rise in temperature of 0.000001°C. may be detected.

Langley's Bolometer.—This consists of a Wheatstone bridge, the arms being formed of two extremely thin blackened wires of equal resistance; if the temperature of one changes, the equilibrium is disturbed and the galvanometer affected.

Chemical Action of the Red and Infra-Red Rays.—For a long time it was supposed that this part of the spectrum was incapable of chemical action. Becquerel, however, observed that the red rays affect silver chloride, which has been previously exposed to light for a short time. Draper succeeded in photographing the beginning of the infra-red spectrum, but it was not until Abney prepared a special bromo-silver emulsion—sensitive to the infra-red—that complete photographs were produced. He has obtained photographs of the solar spectrum up to wave lengths of 2700 $\mu\mu$, both with a prism and a grating, and also photographed a number of absorption spectra.[1] The most complete photograph of this region is due to Langley, however.

The ultra-violet region in the solar spectrum does not extend beyond about 300 microns. With an increase of temperature the spectra tend to develop into the violet. Hence, on account of the extremely high temperature of the sun, a considerable portion of its spectrum must necessarily escape observation. In this connection the reader is referred to Chapter XVI. Suffice to say here that according to Langley[2] it would take nearly 100 feet of map to depict on a prismatic scale the spectrum of the ultra-violet region, though it is caused by but a small fraction of the sun's energy, so monstrous is the exaggeration due to dispersion of the prism. It really contains much less than the one-hundredth part of the total solar energy which exists. the visible spectrum containing perhaps one-fifth the energy of

[1]Landauer: Spectrum Analysis.
[2]Langley: Smithsonian Reports, p. 684.

the sun." The length of the spectrum beyond the violet is still unknown, the researches of Schumann giving the shortest wave length yet recorded photographically, the only means available for the chemical end of the spectrum other than their fluorescing properties, and its wave length is 1200 units. The lengths of the waves produced by the oscillating corpuscles of this region are extremely short, and it is supposed that they continue to become shorter until they become electro-magnetic Roentgen waves.[1]

Iron vibrates at many different rates and its spectrum is the richest in lines; they are distributed over every part of the field. It beats with 480 different velocities.

Kayser and Runge[2] measured more than 4500 lines, and on comparing them with Rowland's solar atlas between 520$\mu\mu$ and 320$\mu\mu$, they were unable with certainty to detect a single line which does not appear in the solar spectrum. Cornu photographed the more prominent lines in the ultra-violet, i.e., between 410$\mu\mu$ and 295$\mu\mu$. This region was extended by Lieving and Dewar between 295$\mu\mu$ and 230$\mu\mu$. It is because of the arc spectra of iron that it is valuable therapeutically.

If the length of the light spectrum be placed at one, that of the heat spectrum is 13, while that of the chemical is unknown.

Fraunhofer or Black Lines of the Spectrum.—Fraunhofer in 1824 observed the coincidence of these sodium lines with the double D-lines of the solar spectrum. In his study of absorption spectra Kirchhoff proved the nature and origin of these delicate dark parallel lines which web themselves across the solar spectrum. Fraunhofer discovered them by the use of a telescope. Kirchhoff explained the reason for their existence. If two waves, formed by the oscillations of their light corpuscles, exactly alike, interfere, both are totally destroyed.

Illustration of the Interference of Waves.—Let two

[1]Larkin: Radiant Energy.
[2]Quoted by Landauer.

stones be dropped in water at some distances apart. The waves to which they give rise will expand in circles; in a short time the two circles will collide; but if two waves in opposite phase meet, the water will be at rest and a cork floating thereon will not oscillate. It is a principle of wave motion that waves interfere. If two water waves interfere, rest succeeds; if two light waves darkness. Therefore, concludes Larkin, whose simile is used, stillness in water corresponds to darkness in the midst of light, for light added to light may produce darkness.

Take sodium, for example. When sodium is heated hot enough to be torn apart, either in a Bunsen burner or by the electric arc or spark, two bright yellow lines will flash out, and all the other portions of the spectrum will be black. This is because the metal sodium can only vibrate at two rates, that is, it can only be torn into corpuscles at these two rates, and, therefore, the whole of the spectrum other than these two yellow lines is black. The metal sodium, the basis of common salt, is omnipresent, for the ocean spray as it evaporates in the air leaves minute particles of salt in suspension. As little as 14 millionths of a milligram of sodium is sufficient to project the well-known sodium lines. The rustling of a paper, or movement of a hand through the air is sufficient to arouse a hurricane of these particles. In the act of examining the spectra of any given substance they fall into the source of heat, are instantly torn into corpuscles hundreds of millions of times smaller; and these set up their own waves which enter the slit.

If a strong white light concentrated into a beam be sent from an electric arc, through the flame in which the sodium has been torn apart the bright yellow lines will vanish, and all the other parts of the spectrum appear, save in the two places occupied by the bright sodium lines, which now, however, are black.

If, instead of the arc light, sunlight be sent through the yellow flame the two black lines in the yellow region of the solar spectrum become blacker than before. The corpuscles

of sodium can only oscillate at the two rates and at no other. Therefore the yellow flame lets every other color rate due to oscillating light energy through without hindrance, and absorbs the yellow producing the black lines. This discovery of the fact that the black lines were due to absorption led to the formation of the following law by Kirchhoff:

All modes of matter when vibrating at their own rates absorb the same waves they are able to generate.

Since the solar spectrum has dark lines where sodium, iron, etc., give bright ones (see frontispiece), it is assumed that around the solid, or more probably the liquid body of the sun which throws out the light, there exists a vaporous envelope which, like the sodium flame of the illustrative experiment, absorbs certain rays, namely, those which the envelope itself emits. Therefore those parts of the spectrum which, but for this absorption, would have been illuminated by those particular rays, appear feebly luminous in comparison with the other parts, since they are illuminated only by the light emitted by the envelope and not by the solar nucleus; at the same time the conclusion is forced that in this vapor there exist the metals sodium, iron, etc. Each condition of matter when its corpuscles are vibrating at their own characteristic rate causes different sets of waves, varying in length, amplitudes and periods of oscillations. All the 80 or more modes of matter which the analytical spectroscopist has caused to vibrate in front of the slit of the spectroscope by heat, as in the electric arc between carbon terminals into whose positive crater metals were placed, cast in their respective spectra the same lines as those found in the solar spectrum, demonstrating their presence in the gaseous envelope.

Absorption Spectra.

The absorption spectrum of a substance corresponds with its emission spectrum at the same temperature and in the same molecular condition.

This law, the law of exchanges, was established by Kirchhoff in 1859, as a result of his study of absorption-spectra, viz., the relationship between emissive and absorptive power of all substances for light of the same wave length.

The fact that reflected light is of less candle-power than the impinging light leads up to one of the most interesting and important phenomenon in light physics, and one that is especially valuable in its physiological relation, viz., that of absorption.

Absorption of light energy does not mean its loss; on the contrary, whenever and wherever the phenomenon of absorption is observed, there is work done. Throughout the subsequent chapters of this volume, it is referred to again and again as of great importance. No energy is lost. This is according to the law of conservation of energy. The extinction of energy in space or its absorption and consequent disappearance in matter is one of nature's fundamental truths. When absorbed, it is converted into other forms of energy of equal value. When the waves of light fall upon a growing plant, for example, they do work. They are said to be absorbed, and the green leaf absorbs all the frequencies of light energy save the green which are reflected. In the light-absorbing substance a transformation takes place, beautifully shown in the green leaf by the chlorophyll function. In the appropriation and selection of waves by matter, whatever its nature, the light is sensibly weakened, as in passing through the substance a part of its energy has been absorbed.

Every black line in the solar spectrum is an absorption letter, by means of which the waves that are absent may be read.

Absorption spectra are usually observed at low temperatures.

Fluorescence and Absorption.—The phenomena of phosphorescence and fluorescence are associated with absorption of light.

Certain substances become luminous by the action of light; if the luminosity ceases upon the withdrawal of light they are said to be fluorescent (see Fluorescence, Chapter XVI.), whilst the term phosphorescent is applied to substances which continue to be luminous after the light is cut off. In accordance with the law of conservation of energy, the rays causing these phenomena are absorbed, fluorescent bodies exhibit corresponding absorption spectra, and as they absorb the ultra-violet more or less completely, they all fluoresce in this region of the spectrum.

Phosphorescence.—Under the name of phosphorogenic rays Becquerel has described the rays given by phosphorescent substances.

These are rays which have the property of rendering certain objects luminous in the dark after they have been exposed for some time to the light. This is a species of luminosity very closely allied to fluorescence. Indeed, according to Becquerel, who discovered this property in luminous rays, fluorescence is only phosphorescence of very short duration. He distinguishes between the rays which originated the luminosity, the exciting rays, and the continuing rays to which he gave the name of phosphorogenic rays.

In fluorescent bodies the radiation exists only during the time the body is exposed to the exciting rays of light. In phosphorescent bodies, however, the radiation persists after the exciting cause is withdrawn. Among some of the natural and artificial substances which have the quality of phosphorescence may be mentioned diamonds, calcareous spar and sulphide of calcium. The latter is the best and most brightly phosphorescent substance known up to now. It is called after its discoverer, "Balmain's Luminous Color."

Artificial phosphorescent bodies include the sulphides of the alkali earths, which are obtained by heating sulphur with limestone, barytes or strontium salts.

Color of Phosphorescent Light.—The colors of phosphorescent light depend not only upon the chemical constitu-

tion of the substances which emit them, but also upon the physical nature and temperature.

Intensity of Phosphorescent Light.—The intensity of phosphorescent light is increased by heating. The waves of phosphorescent light, as those of fluorescent light, are of greater length than the exciting light. There is considerable evidence to indicate that in phosphorescent light energy is given off, which has been taken from the absorbed light of the exciting light source. This is in accord with physical laws, for absorption means work done or energy imparted. Phosphorescent light always has a far weaker light than the light acting to produce the phosphorescence. It has been calculated that the light of the best and most brightly shining phosphorescent substances excited by daylight, when in immediate contact with bromide-of-silver gelatin plate, acts about as powerfully as the light of one normal candle at 50 centimetres distant.

Phosphorescent Light Renders Visible the Infra-Red Spectrum.—Becquerel and Seebeck discovered that yellow and red rays counteract the action of the violet rays, in other words, extinguishing or at any rate considerably weakening the brightness produced by them.

As fluorescent plates or the substances are used to render visible the ultra-violet spectrum (see Chapter XVI.), so phosphorescent plates were used by Becquerel to make the infra-red visible. For example, if a plate covered with Balmain's luminous color, which has been exposed to daylight, and is, therefore, luminous, is then exposed to the infra-red spectrum, i.e., the dark, at first the spectrum bands become brighter, the Fraunhofer lines remaining unaltered. This soon changes and the Fraunhofer lines gain in luminosity until they appear bright on a dark ground.

Duration of Phosphorescent Light.—This varies with different bodies. There is no connection between the intensity of the phosphorescent light and the duration of the luminosity.

Absorbed Light, the Action of.—From a study of the

physical effects of light we find that absorption is a most important phenomenon of light energy. The appropriation and selection of waves by matter and their eventual return to space constitutes the life of the universe. None of this absorbed light is lost.

Heating Effects and Calorescence.—(1) It is transformed into heat; the rays which fall upon a body heat it and are emitted as obscure heat rays of greater wave length, the reverse of which is true. The body upon which obscure heat rays fall may be heated till it shines. To this phenomenon Tyndall gave the name of Calorescence.

Fluorescence.—(2) In certain substances absorbed light causes the immediate emission of new light rays of different colors. This is known as Fluorescence. (See Chapter XX.) The luminosity of these bodies exists only through the period of their lumination. The color of the light emitted is different, both from the impinging light and from that of the body itself. Reflected rays cause the colors of bodies, but the coloring of fluorescent bodies is due to the absorbed rays.

Phosphorescence.—(3) A more or less continuous emission of new light rays of different colors is produced by absorbed light. To this is given the name of phosphorescence, of which a notable example is sulphide of calcium.

Chemical Effects.—(4) Chemical effects may be produced; notably decomposition. The most intense chemical energy of the spectrum is found at the extreme or ultra-violet end. All frequencies from blue up to ultra-violet are also chemical in their action but less than those of the ultra-violet. Light exerts a chemical action in numerous phenomena. For example, silver chloride blackens under its influence; transparent phosphorus becomes opaque; vegetable coloring matters fade; hydrogen and chlorin gases when mixed combine slightly in diffused light and with explosive violence when exposed to direct sunlight.

Scheele found that when silver chloride was placed in violet the action was more energetic than in any other part; but it was further observed by Wollaston that the action ex-

tended beyond the violet. This chemical action of ultra-violet energy is fully considered in the chapter devoted to that subject.

Photography is based on such effects.

Mechanical Effects.—(5) Light energy under certain conditions produces mechanical results (illustrated by Crookes' Radiometer).

Electric Phenomena.—(6) By the vibrational activity of the oscillating light corpuscles, in many instances, electric phenomena are caused.

The Relation of Colors of Bodies to the Colors of the Spectrum.—The color of a body is not identical with the color of the spectrum, but is dependent on the light striking it. Certain component parts of the light are absorbed by the body which reflects or permits the passage of the others. In the one instance it is opaquely colored and in the other transparently colored. There is, then, no color in bodies, the color is in the light. The transparent body is transparently colorless if it permits the equal passage of all parts of the impinging light. For example, it is transparently blue if it absorbs all but the blue light. Blue solution of copper sulphate absorbs the red and the yellow chiefly and permits the passage of the green and violet; but not so freely as blue, hence it takes on a blue color.

Yellow color solutions permit of the passage of the yellow rays, less freely the red and the green, absorbing the blue and the violet entirely.

The whiteness of an opaque body depends upon its ability to reflect equally and strongly all the component parts of white light; if black it absorbs them. Of practical interest in this connection is the fact that colorless bodies which are equally transparent to light may vary very greatly in the degree to which they permit the passage of the chemically active rays. For example, rock salt and quartz absorb them least of all: "Double-spath-soda" absorbs these rays less than crown glass and flint glass.

The red frequencies penetrate bodies much more readily

than do the blue. A spectrum analysis of lamplight which has been passed through a thick sheet of paper will show that all blue light has been absorbed and that only the red and yellow remain.

If the absorbing layer be thicker, the red only will pass through. The same holds good of gases and vapors, as the atmosphere, for example. The matter of atmospheric absorption is a matter of constant reference in the pages which follow.

Absorption takes place the more readily, the sharper the light at which the angle is reflected.

Properties of the Spectrum.—The spectrum is regarded as possessing luminous thermal and chemical properties. As pointed out in relation to many different aspects of the subject, these properties are not inherent through any single frequency or a group of frequencies, but they exist in all of the different frequencies of the spectrum according to the substance upon which the light falls.

The thermal effects are considered in the Physics of Radiant Heat as well as in the therapeutics of the subject of light energy, while the chemical effects especially considered in Chapter XVI. form an inherent part of every aspect of the subject of light energy in its physiologic and therapeutic relations.

Spectroscope.—The spectroscope is not only useful for the purpose of analysis of solar light but it also sustains a relation to the use of light in therapeutics: (1) In experimental work where it is desirable to exclude all but certain frequencies of light vibration; (2) to carefully analyze the light allowed to penetrate into rooms in which patients suffering from smallpox or the exanthemata are placed; (3) to analyze the spectra of the different sources of light used by the physician; (4) for the purpose of investigating substances which have a special importance in physiology and pathology, normal and diseased blood, for example. The first is illustrated by experiments of Bernard and Morgan upon bacteria, the second by the preparation of the Finsen red room.

The Spectrum of each Light Source Varies.—The light-giving power in the several parts of the spectrum from various sources of light is well illustrated by the following classic table:

	C Red.	D Yellow.	C′	F ½ G. Blue.	Total light power expressed in normal candles.
White light	73	100	104	134	1
Gaslight	74	100	103	125	16
Lime light	59	100	113	285	90
Electric Arc light.	61	100	121	735	362
Magnesium light	50	100	223	1,129	215
Moonlight	87	100	155	363	204
Sunlight	45	100	250	2,971	70.000

An analytical glance at this table will show the very great preponderance in sunlight from the F½ to the G line in the energy of the blue, which all of the evidence thus far elicited has shown to be so valuable, physiologically and therapeutically. A glance at the continuous solar spectrum will still further emphasize this fact.

Magnesium Light.—The light next rich in the very valuable rates of oscillating light energy is the chemically active magnesium light, which, as compared with the sun, is as 1,129 to 2,971. This is the most intensely active chemically of all sources of artificial light, but it burns away with very great rapidity so that it is impossible to keep a continuous powerful illumination, as is necessary in all therapeutic work. Additionally it gives off a great deal of smoke, which precludes the possibility of using it for therapeutic purposes, rich as it is in the blue frequencies and powerful as it is photographically.

It will be seen from the pages which follow upon the electric arc that it amply fulfils the conditions for an artificial source of light energy.

Influence of Atmospheric Conditions.—Ultra-violet absorption, according to Cornu,[1] is essentially due to the nitrogen and oxygen of the air, although it is generally attributed to the presence of the varying constituents of the air, water vapor, carbonic acid and dust, factors which may possess a contributory effect. All wave lengths of less than 307$\mu\mu$ are thus absorbed. This absorption is also influenced by the movement and the temperature of the air.

[1]Landauer: Spectrum Analysis.

According to Rowland's tables of wave lengths, the water vapor and oxygen of the atmosphere are the only substances which produce absorption in the visible region, while nitrogen, carbonic dioxide and ozone appear to exert no influence.[1]

Thus, it will be seen, that the absorption varies greatly for the different frequencies. The violet which are the chemically active frequencies suffer more than the green and yellow, which are the most effective in the growth of plants; and these again more than the red; and the red, in their turn, much more than the low pitched slowly vibrating waves below the red which, though invisible, are still powerful carriers of energy. Generally speaking, according to Young[2] it may be estimated that at the sea level, in fair weather, neither excessively moist nor dry, about 30 per cent. of the solar radiant energy is absorbed when the sun is at the zenith, and at least 75 per cent. at the horizon. Of the rays striking the upper surface of the atmosphere, between 40 and 50 per cent. therefore are generally intercepted in the air even when there are no clouds.

According to Langley the following percentage of the frequencies of the different regions of the spectrum pass the atmosphere:

Ultra-violet	39 per cent.
Violet	42 " "
Blue	48 " "
Greenish blue	54 " "
Yellow	63 " "
Red	70 " "
Magnesium light: Infra-red	76 " "

[1]Landauer: Spectrum Analysis.
[2]The Sun, Young.

The Electric Arc.

Over a hundred years ago, March 20, 1800, Volta wrote his first letter announcing the discovery of his pile.

Upon this discovery the scientific world was as much agape as in these latter days it has been over the discovery of the X ray by Roentgen, of Becquerel rays by Becquerel, and more recently still the discovery of radium, with all its wonderful significance to pure science by Professor and Madame Curie. The experimental investigation of the early days of the voltaic pile may be classified as follows: (1) "Those which dealt with the effect of the current on living things. (2) Those which produced chemical decomposition of inorganic matter, particularly of water. (3) Those which dealt with the heating power of the current, more particularly with the sparks produced by making or breaking a circuit."[1]

It was this last series of experiments which led to the discovery of the arc.

At the time of Volta's discovery and subsequently, one of the earliest experiments was to make a spark by bringing the two terminals of a battery together, in order to show that the current from the pile of Volta was of the same nature as "common electricity," so well known to the physician of to-day as static electricity.

This was accomplished by many observers, but Sir Humphry Davy, October, 1800, was the first to try the effect of two well-burned pieces of charcoal as the conductors. Charcoal had already been shown to be a good conductor of electricity by Priestley.

Davy reported that he found that this substance possessed the same properties as metallic bodies in producing the shock and spark which made a medium of communication between the ends of Volta's pile.

In a lecture before the Royal Institution in 1801, Davy stated that the spark passing between two well-burned pieces

[1]The Electric Arc, Aryton, p. 20.

of charcoal was larger than that passing between brass knobs "and of a vivid whiteness;" an evident combustion was produced, the charcoal remained red hot for some time after the contact, and threw off bright corruscations.

Thus was conceived the idea of the electric arc. But there was no continuity to the phenomena observed by Davy. It was only the discontinuous spark. The very nature of an arc requires continuity, and that the two poles should not be in contact after ignition. Later, in 1802, Davy reported to the Royal Institution that he had tried the effect of the electrical ignition of dry charcoal upon muriatic acid gas confined over mercury, with the result of making the charcoal white hot by successive contacts for nearly two hours. Had there been the proper relation between the E. M. F. and R. of both the internal and external circuits, the continuity of the spark obtained would have been established and the electric arc then and there would have become an accomplished fact.

The batteries of that earlier time were so constructed as to have a very great internal resistance, i.e., small plates. Fourcroy, Vacquelin and Thenard, in 1801, discovered that this resistance could be lowered by the use of larger plates, and it was soon found that fewer and larger pairs of plates gave better results in the production of sparks and heating effects than a greater number of pairs with small plates.

Numerous experiments were made in 1801, on the continent, with the spark thus obtained from the contact of the two terminals of the voltaic pile, in France by Fourcroy, Thenard and Vacquelin, and in Germany and Austria by Ritter, Thormsdoff, Gilbert and Pfaff.

Gold and silver leaf, as well as thin wires, were burned, causing flames to arise between the two poles. In some instances a single spark was obtained. in others a continuous and rapid succession of sparks, but the experimenters failed to differentiate between them, therefore "the actual discovery of the electric arc, both as to discoverer and time, is shrouded in mystery."

Frictional electricity, with which scientists had worked up to that time, presents the phenomena of a succession of sparks always, when the mechanism is in operation, and, therefore, the first observer of a succession of sparks from a voltaic pile was in all probability unimpressed by the phenomena.

An electric arc is after all but a spark, but it is a continuous spark, maintained after first contact of the two terminals or electrodes, even though there be a space between the electrodes, and to insure such continuity there must be the necessary and definite relation between the electro-motive force and the resistance as well as the proper feeding arrangement of the mechanism.

Sir Humphry Davy was the first to describe this long horizontal arch of flame by reason of which the arc is named, although, as stated, it will never be known to whom the actual discovery should be accredited. To him, however, is due alike the conception and description, and in 1820, after he had shown that the flame was deflected by a magnet, first predicted by Arago, though unknown to Davy, the latter gave to the phenomenon the name of the *arc*.

It is not generally realized by physicians using static machines that to the discharge of the spark gap from a frictional machine, the first conception of the arc is due, although not until Volta's discovery was it possible to establish the necessary conditions. To recognize the kinship of all these various manifestations of energy, luminous and electrical, is to unify one's knowledge of these agents to the end of their more intelligent use in therapeutics.

The development of the electric arc to its present practical position has been the result of many years of study, investigation and experimentation, the history of which, all down through the nineteenth century, is one of great interest, and the student will find an extensive bibliography upon the subject replete with interest and useful knowledge.

The difference of potential, in spark discharges and also in the discharge from a point, between the electrodes is very

great, several hundred volts, but the current is only a fraction of a milliampère. This is not only true of the spark discharges but also of the convective discharge from a static machine with which one is so familiar. With the electric arc, however, when the electrodes are in a state of incandescence, the potential difference is very much smaller, while the current is enormously greater, often amounting to many ampères.

When two carbons or conductors of other metals are brought together and slowly separated, the electric current does not immediately cease to flow; in other words, if the carbons or rods are not too widely separated, the circuit is not broken, but the space between them is traversed by a cloud of highly heated metallic vapor which carries the current. And although the current passes, there is no spark produced in the air, as for example, with the static machine or a high-tension coil, because there is not sufficient difference of potential to produce a spark in air. The electric current is assumed to flow from the positive pole of the source of E. M. F., through the circuit to the negative pole. In an electric arc, the direction of the current is the same from the positive carbon rod or electrode, across the gap formed by the interruption of the current, to the negative rod or electrode that it may reach the negative pole of the source. But when the carbons are separated about one-tenth of an inch, 3 mm., an arc of violet-colored light is formed between them, and the ends of both become brightly incandescent, the positive more than the negative. This incandescent cloud of vapor formed between them assumes a bow or arc-shaped form. This bow shape exists even when the carbons are vertical owing to the magnetic action of the earth's lines of force on the current. This arc may be a carbon arc. an iron, silver, cadmium or a copper arc, taking its name according to the metals employed. The color of the arc and the character of the spectrum produced by it depends upon the nature of the contacts or electrodes employed.

If copper is used, the light takes on the greenish coloring characteristic of copper. With iron there is an intense dead bluish white light with a great deal of violet coloring. With carbon contacts the light produced is of a vivid dazzling whiteness. This has the quality of sunlight. The light from a carbon arc more nearly approaches the quality of sunlight than the light of the metallic arcs referred to, and should, therefore, preferably be selected, when it is desired to utilize the activities of the electric arc for the purposes of a general therapeutic administration, for example, in an exposure of the entire nude body to all its radiant energy. Not only should it be a carbon arc but a solid uncored carbon, because the softer core sometimes used to secure the greatest liberation at the center volatilizes at a lower temperature, the arc is confined to a limited area, and, therefore, there is less of the blue frequencies than with the solid core. This does not refer to an iron core. Different substances volatilize at different rates, and the place in the spectrum of any given metal depends upon the rate of vibration or volatilization of that metal. For example, in a wick which has been saturated with a solution of common salt, then dried and exposed to the action of heat, the heat volatilizes the metal sodium, tearing its particles away from their union with chlorine. The sodium particles vibrate at their own rate, and the flame is filled with dense yellow light. If this light be passed through the slit of a spectroscope, two brilliant yellow lines will be seen in the spectral field, in exactly the same position as Fraunhofer's black lines, but the remainder of it will be dark. This is because sodium is only able to vibrate in two rates.

The blaze from a driftwood fire at the seashore gives a spectrum rich in yellow, because of the impregnation of the wood by the salt of the ocean. Sodium of all metals possesses the greatest spectral sensibility, and it has been ascertained that 1/200000000 of a grain of sodium is enough to cause the appearance of the yellow line. The rates at which different metals vibrate, dependent upon the

temperature at which they volatilize, can readily be seen from Plate 1. Bodies at a red heat give only a short spectrum, extending at most to the orange; as the temperature gradually rises, yellow, green, blue and violet successively appear, while the intensity of the colors near the lower end of the spectrum increases. In Plate 1, colored, the spectra of certain substances examined with the spectroscope are shown.

If the physician will examine for himself the spectra of his light apparatus he will have a very vivid picture before him of the rates given off by the source of light he is using, and as to its richness in the chemical frequencies, so precious in therapeutics.

Returning, however, to the electric arc, a strong current flows when the carbon rods are brought into contact and just before separation the resistance is very great. By reason of this great resistance the carbon is raised to a very high temperature and a portion of it is converted into carbon vapor, which is a sufficiently good conductor to allow a steady current to flow through it.

The temperature necessary for the volatilization of the carbon is not reached at the extremities of both rods, but only at the positive. The temperature of the negative, except at its extreme point is always considerably lower than that of the positive. The difference is due to the fact that the larger part of the energy is transformed into heat at or near the surface of the positive carbon. The average length of an electric arc is 3 mm., but the distance between the carbons which govern the length of the arc, varies with the kind of carbon and with the active electro-motive force.

The crater formed at the end of the positive carbon is due to the combustion of the carbon, and the shape of this crater depends upon the length of the arc. In appearance the crater of the positive carbon suggests the crater of a volcano. The end of the negative carbon is conical shaped. This is due chiefly to combustion, but is contributed to by

the deposition of particles of condensed carbon vapor from the positive pole, which help to build it up. Both terminals lose weight, but the positive more rapidly than the negative. This description applies to the carbons of a direct-current arc.

These particles of boiling carbon can be seen floating off from the positive carbon by projecting the image of the arc on a screen or blank wall. Part of them float off into the surrounding media and part in a condensed form, as has been stated, are conveyed to the end of the negative carbon. This is a characteristic action of the current, and partakes of the nature of cataphoresis or the actual transfer of substances, from the anode to the cathode.

The crater of an electric arc has a very high temperature, that of boiling carbon, 3,500°C. or 6,332°F. as proved by Violle, the interior of which is the brightest part of all. The intense heat thus generated can be realized when the melting point of platinum is considered, which is 1,775°C. or 3,219°F. The size of the crater varies with the size of the carbons and the amount of current consumed. The temperature of the negative carbon is between 2,100°C. or 3,772°F. and 2,500°C. or 4,532°F. This tremendous temperature of the electric arc renders it very efficient in electric welding and in operating electric furnaces. Both temperature and luminosity are chiefly due to the conversion of electric energy into heat, but are partly derived from combustion of the carbon in air.

The dazzling brightness of a carbon arc, a miniature sun in fact, is such that it can only be observed through smoked or densely colored glass. Upon examination in this way, the observer notes that the arc or bow-shaped bluish flame which appears in the gap between the two opposed carbons is very much less brilliant than the ends of the carbons themselves. The characteristic change in the shape of the arc will be noticed after it has been maintained for a short time, i.e., the end of the positive electrode is hollowed out in the form of a small crater, while the negative

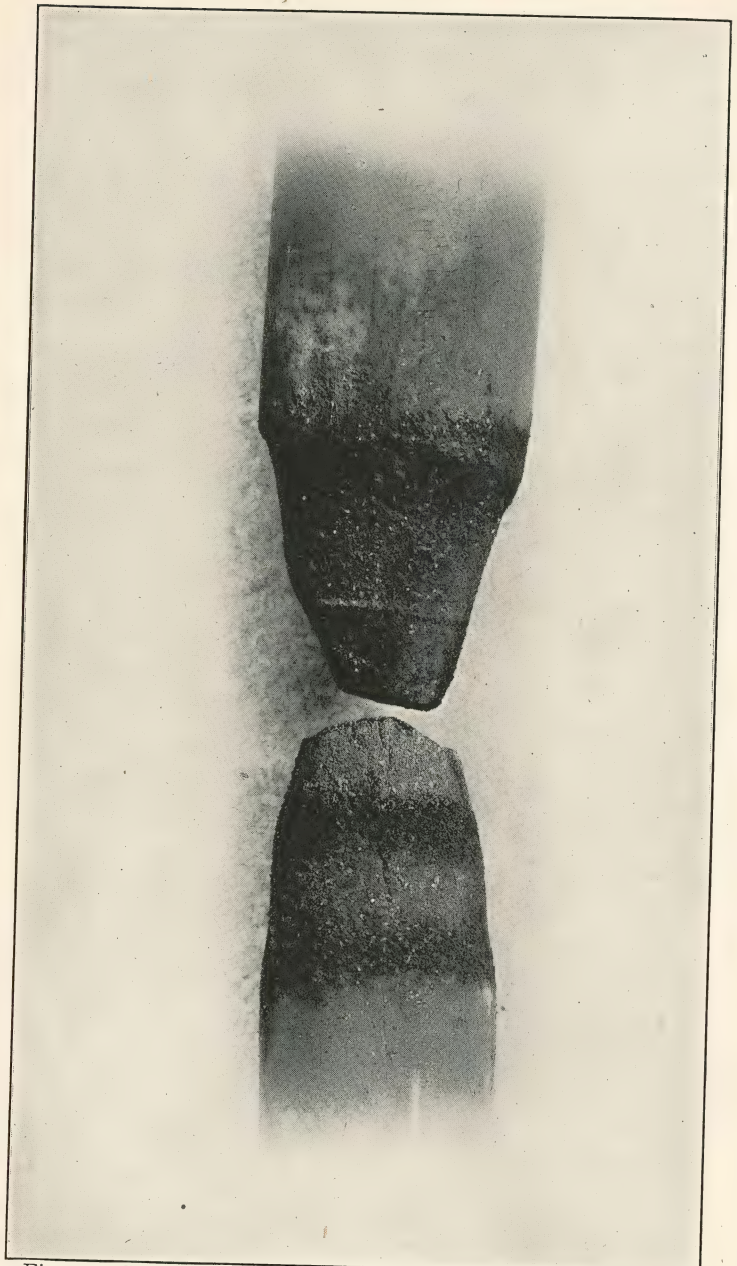

Fig. 1.—Carbons used in clinical work with a 25-ampère arc. The upper or positive carbon shows the crater-like depression, the lower or negative carbon the nipple-like projection. The area of incandescence is clearly shown as well as the disintegrating action upon the carbons under the double influence of volatilization and oxidation.

or opposed carbon has a minute nipple-like projection formed on the end just opposite the crater in the positive carbon. The positive carbon is brighter than the negative, but most of the light, however, issues from the crater itself. As the power of any body to emit light increases with its temperature, an inspection of the arc quickly confirms the statement made that the crater is the hottest part of the arc.

With the current strength ordinarily employed, the incandescence of the carbons extends to but a comparatively short distance from the tips. This is the region in which the burning of the carbons or the oxidation is most marked. After the arc has been maintained for awhile under the double influence of volatilization and oxidation, the ends of the electrodes assume a more or less irregular shape. This is shown in Fig. 1.

Careful observation, through the medium of smoked glass, of the conical-shaped ends of the carbons, will reveal minute globules of molten matter, scattered here and there over their surfaces. These are supposed to be molten drops of various mineral impurities in the carbon. The more nearly pure the carbon the fewer they will be. If an iron cored carbon, positive, is used, there will be observed tiny drops of molten iron on the tip of the negative.

In operating an arc, the crater does not maintain its position, but shifts from point to point on the surface of the positive carbon or electrode. This is explained by the following fact. As the carbon is consumed by volatilization and oxidation, the edge of the crater becomes unequally worn at different parts, and the tendency is for the arc to establish itself at the point where there is least space between the two carbons. In this way a new crater is temporarily formed. Impurities in the carbons also determine a different rate of volatilization with the result of the formation of the crater at the point where volatilization is most active. It is very essential for the best results, whether as an illuminant only or whether it is to be employed therapeutically as a minia-

ture sun bath, that carbons of the greatest purity should be used.

By reason of the shifting of the position of the crater from the above causes, the light becomes unsteady and flickering, which results in an unequal distribution over the surrounding space. This has been obviated in the practical operation of the arc by utilizing carbons of the smallest diameter compatible with the amount of current consumed in order to reduce the area over which the arc can shift, and also by the introduction into the centre of the carbon a core of softer carbon. By the use of such a core, there is secured the greatest liberation from the central portion, and the consequent formation of the arc at these parts. These are known commercially as cored carbons. Usually but one carbon is cored, viz., the positive, as this is the seat of the crater, where the trouble arises with the ordinary carbons. In therapeutic work cores of iron, an iron rod passed through the centre of the carbon axially, or iron incorporated into an appropriate solidified mass are used. As iron when volatilized is extremely rich in chemical activities, its use is very desirable where the production of the maximum of ultra-violet rays is desired.

By reason of the rapid vaporization of the positive carbon it wastes twice as fast as the negative. This is the reason why it is necessary where large currents are used that the positive carbon should have twice the thickness of the negative carbon.

The arc proper is separated from the crater by a thin layer of carbon vapor, which has in all probability a high specific resistance. This layer of carbon vapor is of bulbous shape, violet in color and consists of conducting carbon particles condensed from the vapor.

The region around the arc in which the combustion is going on is distinguished by a green flame. Eighty-five per cent. of the light of the arc comes from the positive carbon, 10 per cent. from the negative, and 5 per cent. from the arc proper. Although the temperature of the arc is high, its

emissive power is feeble. The sources of light in the arc are (1) the crater, (2) the remainder of the hot end of the positive carbon, (3) the white hot spot on the negative carbon, (4) the remainder of the hot end of the negative carbon, (5) the arc vapor.[1]

The light emitted by these 5 sources together is called by Mrs. Aryton the light of the arc; while the light emitted by the arc proper she terms the vapor light, or the light of the vapor.

It is this vapor light which concerns the physician. As has been shown the color is that of violet, and from it proceed the short high frequency wave lengths or ultra-violet rays as well as the blue and violet, all of which have well-marked actinic properties. The longer the arc the more of the vapor mist. This means that the arc mist would be cooler as the average temperature of it is lowered by increasing the length of the arc. As the carbons are drawn apart, the arc stream tends to spread out further. The amount of light emitted by the unit area of the crater is practically the same when the power supplied to the arc is raised sixty-fold, and is independent of the size of the carbons and of the length of the arc. This was demonstrated by Violle.[2]

By increasing the current, with given carbons, at a given distance apart, the size of the crater is increased, and therefore the total amount of light emitted, but there is no increase of the amount per unit of area. If the temperature of the crater is that of the volatilization of carbon, it could not be increased, provided the pressure remained constant, however greatly the power applied was increased, and therefore it would not be expected that there would be more light emitted per unit of area. The principle involved is the same as in boiling water. The temperature of boiling water cannot be raised even by using a more powerful source of heat. The

[1]Aryton, p. 314.
[2]Ganot's Physics, p. 869.

temperature of the space between the carbons may be much higher than that of the surface in the same way that steam can be superheated above the point at which it is evaporated, there being in fact, no limit to the possible rise in temperature. Since the current is conducted by that highly heated vapor present, it is to be expected that such a conductor will be heated by the passage of a current the same as a solid or a liquid.

An electro-motive force of more than 40 volts, usually from 40 to 50, is necessary to maintain a steady arc between carbon points, giving a current of 10 to 15 ampères. It is generally assumed that this high E. M. F. is needed because of a back E. M. F. of 39 volts at the crater in the positive carbon. A large amount of energy is needed there for the vaporization of the carbon. This high apparent resistance of the arc, obtained by dividing the difference of potential by the current, is due to this back E. M. F. This counter E. M. F., which is variable with the current and other conditions, is generally attributed to a combination of two or more separate electro-motive forces, one due to the volatilization of the carbon, another due to the thermo-electric effect at the positive carbon, and perhaps still another thermo-electric potential at the negative carbon.

According to J. J. Thomson this potential difference is determined by the rate at which the negative electrons are given off. An arc of 3 mm. or 1/10 of an inch, has a resistance something less than an ohm. For a 10-ampère arc from 1/16 to 1/8 of an inch in length, the resistance is given at from 1/10 to 1/2 an ohm, while roughly speaking a resistance of 5 ohms for an arc one inch in length is given. The true length of an arc is from the bottom of the crater to the tip of the negative, not from the edge of the crater which is only its apparent length. This resistance of an arc, like that of any other conductor, increases with its actual length, and diminishes with its cross section. It has been suggested by Mrs. Aryton that the film of carbon vapor close to the crater has a relatively high specific resistance and that the

temperature of the crater may be accounted for by its resistance rather than assuming a large back E. M. F.

Care should be taken in the adjustment of carbons. If they are too far apart, or too close together, the arc is noisy and fluctuating, and if the distance between them is too great the arc flares and flickers from side to side. Thus the *chemical combustion* is *increased,* with the result that the electric efficiency is reduced when the distance is too small, while the illuminating power of the arc is reduced by each carbon acting as a screen for the other, and the crater is diminished in size. By the reduction in size of the latter, the efficiency of the arc in therapeutic work is diminished, for the longer the arc and the larger the crater, the greater number of the short high frequency waves or ultra-violet light, intrinsically so valuable. This is because of the increase in chemical combustion. The longer arc offers a greater opportunity for the air to oxidize the carbon. The longer the arc the greater the E. M. F. required, and when more than 80 volts is used there is a great increase in the quantity of violet light given off. This is not well for purposes of illumination, but it is just what is needed for therapeutic work.

There is no difference in the appearance and consumption of carbons when an alternating E. M. F. is used, for by reason of its physical nature changing at both signs, positive and negative, with each alternation, there is no polar action as with the direct current. Each carbon maintains a rounded appearance, there is no formation of a crater and they are consumed at the same rate. The upper carbon wastes 8 or 10 per cent. faster than the negative, due to the ascending heat. When an arc is fed by an alternating current the arc is no longer a continuous flame, but is lighted and extinguished at every reversal of the current.

The candle-power of an electric arc depends upon its volt-ampères. For example, an arc with a pressure of 50 volts, and giving a current of 15 ampères, expends a power of 50 volts $\times$ 15 ampères, or 750 volts. This is equivalent to about 1 horsepower. As .75 of a volt is required to produce

the light of one candle, 750 volts will give 1,000 candles. Therefore if one is operating two arc lamps connected in series, with a pressure of 50 volts and a current of 15 ampères, in an electric arc bath, in which the patient lies nude, the body is bathed in a sea of light of 2,000 candle-power, and while to each square inch of surface but a small amount of light energies are delivered, there is a very considerable total of energy expended by reason of the very large square inch area exposed, i.e., the entire body. This effect is increased by reason of the cabinet enclosure and the white enamelled walls, providing as they do the best of reflecting surfaces.

In the Light Institute at Copenhagen, under the direction of Finsen, lamps of 20,000 candle-power are used. This means a tremendous volume of light, and with the increased current, 80 ampères and upwards, and the increased diameter of the carbons or electrodes, there is afforded a larger crater, which means a larger unit of area. And as it is the light emitted by the *arc* proper, called the vapor light or the light of the vapor,[1] which is so rich in chemical activities or short and high frequency waves, from the blue to the ultra-violet, the advantage of lamps of high candle-power can readily be seen. This quantity of light, so active, chemically, is essential in the treatment of well-organized and deep-seated skin conditions, as in long-standing cases of lupus vulgaris for example.

Quantity Necessary as with the Continuous Current.—The good results obtained from the selected chemical activities of the electric arc from lamps of high ampèrage and enormous candle-power, in the treatment of deep-seated and long-standing lesions, is comparable to the use of the continuous current, in long-standing and deep-seated pathologies as for example, exudates about the sheaths of tendons and the articular surface of joints.

From the use of currents of high potential and high frequency it is not possible to obtain results as quickly in these cases as with the chemical action of the continuous current. There is a chemical action with both, but there is not that *quantity*, coulombs per second, with the one that there is with the other, which is essential to the production of the changes necessary to the absorption of the organized exudate. This is likewise true of condenser lamps, excited by high-tension coils or static machines, and also iron electrode lamps of low ampèrage. The chemical activities thus produced have not the *quantity* of the larger lamps, which is absolutely essential in the most thoroughly organized skin pathologies or wherever a deep-seated action is required. For more recent and superficial conditions the lamps of lesser *quantity* are equally good.

[1]Aryton, p. 314.

But lamps of lesser ampèrage do good work if the *light* emitted by the *arc* proper or vapor light is utilized near its source. By their passage through air, the precious ultra-violet waves are absorbed to a greater or less degree, according to the distance. The same is true of that portion of the ultra-violet region known as the bactericidal region when passed through water. It is estimated that four-fifths of the bactericidal activity is lost in passing through but 2.5 cm. of water. And as in the Finsen apparatus the condensing lens is at least three feet from the vapor light emitted by the arc proper, and passes through from 4 to 6 inches of water, there is a very considerable loss. With the enormous candle-power of the lamps used by Finsen, this is of little moment, but with the lamps of lesser ampèrage commonly used in office work, it becomes a matter of very great moment. In using lamps of lesser ampèrage, without water-cooling cylinders and near the arc itself, the difference is not proportional to the diminished candle-power, as in the latter instance few of these short high-frequency waves are lost as compared with the higher candle-power lamps where the beam is not only used farther from its source, but filtered through water. All the energy of the light from the arc, whether in the form of light, heat

or anything else (gases produced), radiates from the middle of the crater.

Measurements which have been made show a correspondence with the compound radiant energy of the sun's surface, viz., at the rate of 100,000 horsepower to the square meter.

There is always a definite ratio between the energy of any body and its temperature, therefore, if the radiant of two bodies is the same, so is their temperature. That of the radiant dot of the electric arc is nearly 6,500°F. This would indicate that the temperature of the sun's surface is the same, in view of the fact of the correspondence in measure of energy.[1]

It has been shown that an increase of pressure does not increase the temperature of volatilization. An increase in the current strength or the quantity of electricity which passes per second through the arc has no increase upon the temperature of the arc, and only tends to increase the amount of carbon volatilized, and, therefore, the area of the crater. This affords, as has been pointed out, an increase in the unit of area.

The temperature of boiling carbon is 3,500°C., and is the highest which has yet been produced artificially. If conditions existed under which a temperature in excess of boiling carbon could be reached, it would mean a source of light richer in the visible and invisible frequency of light, or short and high frequency vibrational activity; a light not only of higher intrinsic energy, but of greater total energy, capable of profounder chemical action, the therapy of which is yet unknown. But iron which volatilizes at a temperature of 1,600°C., although volatilizing at a lower temperature, has a high rate of vibrational activity, and gives a spectrum rich in the ultra-violet frequencies, but it does not vibrate at the slower rate that gives the visible chemical rates and those below, and the light, therefore, while possessing the

[1]Professor Dolbear. Press clipping.

high intrinsic energy does not possess the total or complex of energy essential to the best therapeutic work. In the much lower temperature at which volatilization takes place is to be found the reason why, when an iron-cored carbon is used for the positive electrode in the formation of an arc, the production of heat is so much less than with pure carbon, which volatilizes at a temperature of 3,500°C. or 6,332°F. And this lower temperature in connection with its extreme richness in ultra-violet rays, i.e., inherent rate of vibration, renders carbons with iron cores very desirable for the therapeutist. Iron is used alone in some arc-light mechanisms for therapeutic purposes. Clinically, however, the better results are obtained with the lamps of larger ampèrage where carbons or carbons cored with iron are used, than with lamps of small ampèrage with iron electrodes. As the most intense chemical combustion is the seat of the highest chemical activities, there is every reason to believe that the higher temperature at which the volatilization of the carbon alone or that of carbon combined with iron, is the one at which the greatest quantity of ultra-violet rays are given off, and, therefore, is the better source for therapeutic work.

Bodies become luminous at a temperature of 500°C. or 932°F., but the increase of luminous intensity increases with the temperature. This will not be true of the *cold light* of the future, which will be a light devoid of temperature and containing the maximum of visual rays. The efficiency of the light of the firefly is practically 100 per cent.; in other words, the firefly does not seem to emit any frequency of light vibrations, which are not within the limits of visibility; while all practical mechanisms for the production of artificial light for illuminating purposes requires that the temperature of the luminous body be raised to such a point that the frequency of oscillation of its molecules is such as to cause the emission of light as well as heat. This means much more dark heat than luminous heat, and the work of Tesla, of McFarland Moore, of Cooper Hewitt, in the direction of producing luminous activities without thermal, will unques-

tionably result in a cold light, as the illuminating power of the future.

Professor Langley[1] states that the Cuban firefly spends the whole of its energy upon the visual rays without wasting any upon heat, and is some 400 times more efficient as a light producer than the electric arc, and even 10 times more efficient than the sun in this respect.

The luminous efficiency of the arc lamp is practically as high as that of any known artificial source, being about 13 1-3 per cent., while it is nearly 3 times greater than that of the normal incandescent filament, and about 6 times greater than that of oil or gas flames.[2]

In a consideration of the electric arc for therapeutic purposes the phenomena which take place in the arc mist during the activity of the arc are not only of interest but importance. Since Sir William Abney[3] first announced that the temperature of the crater was that of volatilization of carbon, it has never been doubted but that the stuff of which the arc was composed consisted chiefly of the vapor thus volatilized. It leaves the positive carbon without doubt as vapor, but its temperature must be lowered by the cooling action of the air. It must therefore, be considered at a very short distance from the crater. Of this there can be but little doubt, and in her work on the electric arc, Mrs. Aryton expresses it as her belief that the vapor, in leaving the crater, acts just as steam does when issuing from the mouth of a kettle. Through a short distance, small enough for its temperature to continue unaltered, it still remains vapor; at a greater distance it is condensed into carbon, fog or mist. The true vapor is probably invisible, just as water-vapor is (the space that is always between the arc and the crater confirms this view) but the mist is visible. The resistance of true vapor is very great, and consequently the resistance of the thin layer of the vapor that lies over

[1]Electrical World and Engineer, N. Y.
[2]Houston and Kennelly, Electric Arc Lighting.
[3]Aryton, p. 356.

the crater is so great as compared with that of the remainder of the arc, that it is usually supposed not to be a resistance at all but a back E. M. F. According to Stark,[1] there is a back or counter-electromotive force of the arc when the anode is very hot, and it represents the sum of the internal electromotive force of the anode and cathode, but is much smaller than the minimum tension. The latter is not due to the counter E. M. F., but to the fact that a minimum of work must be done at the cathode in order to produce the radiation of negative electrons in sufficient density.

By the passage of the current through this great resistance, the heat evolved (the greater the resistance, the greater the production of heat) is sufficient to volatilize the surface of a part of the positive carbon, and thus to keep up the supply of vapor.

The part of the surface thus volatilized becomes hollow with a short arc, and the crater is formed by the action of the heat supplied to it by the thin layer of vapor over its surface. According to this theory of the arc, the temperature of any horizontal section of the mist must depend upon (1) the temperature at which it left the crater, (2) the constant supply of heat conveyed to it, by radiation from the crater, (3) the heat evolved by the passage of the current through it, and (4) the cooling effect of the surrounding air.

The *average* temperature of the mist must be lowered by lengthening the arc, and consequently its average density must be increased.[2]

The following facts indicate that the arc mist absorbs an appreciable amount of the light emitted by the crater: (1) That this mist shares with candle and gas flames the power to hide anything placed behind it, as if it were opaque, not due to too much light, but absence of light. (2) The acknowledged and proved existence of solid par-

[1]Annales der Physik No. 12; London Elec., Dec. 4, 1904.
[2]Aryton, p. 356.

ticles in it. (3) Its casting a shadow which can hardly be due merely to refraction.[1]

All of these facts concerning the mist are of both interest and importance in connection with the use of the chemical activities of light in therapeutics, as the evidence points to the vapor or mist as their source.

The spectrum of the arc is not only rich in the luminous and thermal activities, but is especially rich in the chemical activities. And by the chemical activities is meant not only those of the ultra-violet region, so much talked of, rich as that region is in intrinsic energy, but the violet and blue violet as well.

The Spectra of the Electric Arc.—The spectra which are formed by artificial lights rarely contain all the colors of the solar spectrum; but these colors are always found in the solar spectrum and in the same order. Their relative intensity is also modified. The shade of color which predominates in the flame predominates in the spectra of that flame. In yellow, red and green flame, red, yellow and green predominate in the spectra. It was shown by Sir W. Abney,[2] as will be seen by tables of light values given below, that the crater light of the electric arc was very like sunlight, but that it had an excess of orange and green rays and a slight deficiency of blue. Taking the intensity of red as the unit, the composition of direct sunlight, of the carbon arc, and of gaslight, were found by Abney respectively, as follows:

Sunlight.		Carbon Arc.		Gaslight.	
Red.......	100	Red......	100	Red......	109
Green.....	193	Green....	203	Green....	95
Violet.....	228	Violet....	250	Violet....	27

The hardness of the carbon, the material of the core, the current and the voltage, all influence the composition of the electric arc. By hardness the maximum temperature

[1]Aryton: The Electric Arc.

[2]Report on the Action of Light on Water Colors, c. 5455, 1888, pp. 25 and 69.

of the crater is determined, while the current and voltage alter the properties of the light fluxes coming from the yellow crater and from the violet arc stream. The vapor of the core acts to color the light as well as to determine the volatilization point of the crater.

Abney's spectroscopic examinations were made so as to interpose as little of the arc as possible between the spectroscope and the crater, and in this way he secured the rays from the crater only. This crater light when seen through a small quantity of mist is yellower than sunlight, but when it has penetrated through a very long arc, the color is a bright purple. This is very commonly shown in the purple coloring of the opalescent globes surrounding the arc lamps of the street. This purple coloring is evidence of great chemical activity. It differs only in degree, not kind, from the violet coloring of X ray tubes and the tubes of glass containing radium. The light of the crater becomes tinged with violet or purple as it passes through the arc, and the tint deepens as the arc is lengthened. In this, then, must be found the reason for the establishment of a long arc when the maximum of ultra-violet rays is required. For next the violet come the higher frequencies of the ultra-violet region.

If a light becomes colored by passing through screens of colored glass, blue, red or green, for example, the explanation is to be found in the fact that the glass interposed, whatever its color, absorbs certain colors and permits other rays to pass. For example, with blue glass, the rays giving other colors are absorbed, therefore a blue glass screen gives the maximum of chemical activities below the ultra-violet region, but not the ultra-violet, however, as glass is not transparent to ultra-violet frequencies, i.e., below 30 micro-centimetres.

The following is a very rational explanation of the phenomena which occur in the electric arc to produce the intense violet mist. The arc, except a thin layer quite close to the crater, consists of a mist of solid carbon particles, which are

continually forming and falling, surrounded by burning gases. The vapor and gases must absorb a minute, possibly an inappreciable portion of the light that issues from the crater. If this were all, there would probably be no maximum of light with a given length of arc, but the solid carbon particles have to be reckoned with. The whole quantity of light absorbed might still be too small to notice, if the light simply passed through each of these particles it encountered and suffered only the small amount of absorption that would naturally occur.

But a ray of light when it encounters a red hot particle is not only refracted, but some of it is reflected, so that each ray may be reflected from particle to particle, and traverse the mist hundreds of times before it finally emerges. At each reflection and refraction part of the light that the carbon particle is capable of absorbing is absorbed, and according to physical laws, a ray that has suffered much internal reflection must emerge in a different state from that in which it left the crater.

If the carbon particles were capable of absorbing the orange light and a certain amount of the green, permitting at the same time the passage of the violet light, then each successive reflection or refraction would result in more violet, while that which had encountered many particles would be entirely violet. A dazzlingly brilliant light is not given by incandescent gases alone, and in looking at the arc mist only, screening off the whole direct light from both carbons, the part of the crater light transmitted to the eye from the solid particles, entirely swamps the feeble light emitted by the gases, and a brilliant violet or purple light is perceived. In this way is the brilliant light of the arc alone accounted for.

A simple experiment shows that the light emitted by the arc *mist* is violet, while that emitted by the crater and the white hot spot on the negative carbon is white. Take a thin metal plate containing a horizontal slit,[1] about 1/16 inch in

[1]Aryton, pp. 358, 359, and 360.

width, hold it vertically near the arc, so that the slit is about equidistant from the ends of the two carbons. Have a vertical white screen a foot or two away upon which to receive the light from the arc that passes through the slit. This light will form three horizontal bands on the screen, the upper and lower ones white, and the middle one of a bright violet. The slit corresponds to a pinhole elongated horizontally, therefore the upper white light proceeds from the negative carbon, the lower from the crater, and the middle violet band is lighted from the mist.

Or again, the upper carbon and part of the arc may be shaded with any opaque body, one's hand, for example. The shadow on the screen is edged with a broad band of reddish violet and represents the portion of the screen that is illuminated by the mist and the negative carbon alone, the red-hot part of the carbon gives the rosy tinge. Below the band is the part illuminated by all three sources,—crater, mist and white hot spot, and this naturally looks quite white when compared with the violet spot.

It is concluded by Mrs. Aryton, whose experiments are quoted, that the crater light is far yellower when emitted than when measured, and as the use of it therapeutically corresponds more nearly to the position of the photometer when it is measured, it follows that the highest chemical activities are easily available for such purposes.

When an arc is lengthened, the arc mist is cooler on the whole and under these circumstances there would be more solid particles, and each ray stands a better chance therefore of encountering one or more of these particles before emerging. Thus, more of the light on the whole would be absorbed, and more of the rays robbed of all the light the particles were capable of absorbing before emerging, so that on the whole, the light would be more violet than with a shorter arc, as it actually is. Every arc-light mechanism used for therapeutic purposes should therefore be adjusted, for as long an arc as its automatic feed arrangement will

permit, in order to secure the maximum violet and ultra-violet rays.

In drawing a long arc, there is ample room for lateral spreading, therefore its resistance is capable of being markedly diminished by an increase of current strength. By spreading laterally in all directions, the cross-sectional area is increased, and an increase in resistance by reason of the length of the arc may be more than compensated by the decrease in its resistance attendant upon the increase in the area of the cross-section. This diminished resistance in a long arc, from which the highest chemical activities are secured, means diminished heat.

Such an arrangement is impractical when the arc is used for illuminating purposes, as "almost the whole of the increased power that has to be supplied to the arc when it is lengthened, is swallowed up by the mist, and is practically wasted. And the ideal condition where illumination only is desired would be to have the carbons nearly touching were it not that the negative carbon stops some of the light."

Professor and Mrs. Aryton, as a result of a series of experiments, combined with careful observation and exact photographic records, found that when a direct current silent arc is maintained between vertical carbon rods, the positive carbon being uppermost,—

I. The tip of the positive carbon is white hot, and the tip of the negative has a white hot spot on it.

II. A white hot crater forms in the end of the positive carbon, and a more or less blunt point forms on the end of the negative.

III. The space between the two is filled by a violet light, the shape of which is defined by a shadow, which in its turn is bounded at its sides by a green light.

IV. The ends of both carbons are tapered, and the length of the tapering parts is increased both by increasing the current and by shortening the arc.

V. The diameter of the crater increases as the current increases, and also as the length of the arc increases.

VI. With uncored carbons, the violet part of the arc is bluer, and all parts of the arc are larger than with cored carbons.

VII. With uncored carbons, the violet part of the arc is of the form of an oblate spheroid when the arc is short, gourd shaped when it is long and the current is very small.

VIII. With cored carbons, the violet part is of the form of an oblate spheroid when the arc is short, gourd shaped when it is long, and sometimes almost of the shape of a figure 8 when the arc is very long for the current flowing.

IX. When the negative carbon is cored, a crater is formed in the tip exactly as if it were a positive carbon.[1]

Hissing Arcs.—It will be noted in operating electric arc mechanisms, that at times the arc gives out a hissing sound. This has been the subject of elaborate study, investigation and experiment by Mrs. Aryton, who has shown that the real, crucial distinction between a silent and a hissing arc is produced by the crater becoming too large to occupy the end only of the positive carbon, and by its, therefore, extending up its side. When the crater occupies the end only of the positive carbon, the arc is silent; but when it not only occupies the end but extends up the side as well, the arc hisses.

The extension of the crater then is the cause, and this extension is due to the presence of air. When an arc is first formed there is always a hissing sound which is due to the presence of air around the carbons when they are cold, so that when the crater is first made its surface must combine with the air; just so when it hisses it is due to an inrush of air into the arc. Hissing is avoided by the use of enclosed arcs, preventing thereby access of air to the arc, but in therapeutic work enclosed arcs should never be used because of the intervention of the glass enclosure.

A hissing arc is accompanied by a sudden diminution of potential difference. This diminution is due to the oxygen in the air getting directly at the crater and combining with

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[1]The Electric Arc, Mrs. Aryton.

the carbon at its surface. No such effect is produced by nitrogen, carbon dioxide or hydrogen, but the same is true of air showing that this diminution of potential difference in a hissing arc is due to the presence of oxygen. With the humming and hissing a green light appears in the crater and with hissing, clouds partially cover the crater; and the carbon vapor becomes flattened out between the carbons.

The student who is interested in the phenomena of the electric arc will find Mrs. Aryton's study of it most interesting.

Alternating-Current Arcs. — Alternating-current arcs may be used for all therapeutic work other than with condensing or focal lenses as in the Finsen tube.

This exception is due to the fact that in an alternating current the direction of the flow is constantly changing and each carbon becomes alternately positive and negative.

In an alternating-current arc there is no crater formed at the end of the positive carbon, nor opposing nipple-like projection on the end of the negative. There is therefore a different distribution of light and the rate of the consumption of the carbons is approximately equal.

Alternating-current arcs are considerably influenced by the frequency of the alternations. If the frequency is below 35 periods or double reversals per second, the arc distinctly flickers. This produces an unpleasant varying visual effect owing to the rapid extinction and production at each pulsation of the current. A frequency of about 60 cycles or 120 reversals per second is generally regarded as the most suitable.

If the frequency is above 70 cycles or double reversals per second, alternating arcs develop a tendency to a distinct humming note which at higher frequencies becomes annoying. But 35 to 40 volts pressure are required by alternating-current arcs. An alternating pressure of 35 volts means a maximum pressure of about 50 volts in each wave, or if an E. M. F., which rises to 50 volts at the peak of each wave be used, the effective E. M. F. will be about 35 volts. The real

pressure required is therefore practically the same for both continuous and alternating-current arcs. There may be a wide variation in ampèrage as with the continuous current but for an ordinary electric arc cabinet 15 ampère arcs are sufficient. In common with continuous-current arcs alternating-current arcs require a regulating lamp mechanism in order to maintain the carbons at a constant distance apart. The character of this mechanism is changed to meet the changed conditions, that is, an almost equal burning of the two carbons. Alternating-current arcs however can never be connected directly with the mains of the generator supplying alternating currents, as they can to the mains of the generators supplying continuous currents. An apparatus known as an alternating-current transformer must always intervene between the mains of the generator and the lamp mechanism. These transformers are provided with both primary and secondary circuits; the primary is connected directly with the generator at a comparatively high pressure 1,000 to 2,000 volts being very commonly used. The secondary circuit is connected with the arc-lamp mechanism or incandescent for that matter wherever installed, usually at a pressure of about 100 volts.

In the event of a single arc lamp being used the pressure is about 33 volts. If however a number of incandescent lamps have to be supplied, a pressure of 100 volts must be generated by the secondary coil of the transformer, but in order to keep this pressure down either a resistance or a choking coil must be introduced to cut the pressure down to 30 volts.[1]

The Influence of a Magnetic Field upon an Alternating-Current Arc.—The alternating-current arc has been shown recently to have characteristics peculiarly its own. C. H. Bedell[2] points out additionally its very interesting behavior when in a magnetic field. That any arc may be "blown out" by the approach of the poles of a magnet is a well-known fact. If

[1] Houston and Kennelly: Electric Arc Lighting.
[2] C. H. Bedell, Electric World and Engineer, Sept. 13, 1902.

a magnet of the horseshoe type be used, "blown out" correctly describes the phenomenon. If a bar magnet is used, the arc is forced out at right angles to the line of the magnet and not directly away from it, as the "blowing out" would lead one to suppose. The principle is the same as that which governs the action on wires carrying current on the surface of a motor armature, i.e., the direction of the flow of the current, that of the lines of magnetic force, and direction of movement are all at right angles to each other. If the north pole of a bar magnet be presented to a direct-current arc and the current flows down, the thrust will be to the right; if up, the thrust will be to the left. With an alternating-current arc, however, the two effects are combined, and the arc appears to have two wings. While these wings appear continuous, they do not exist at the same time, but follow the alternations of the current.

The appearance of the arc under the influence of the magnetic field is interesting, as the wings may easily be made to have an extent of 5 inches from tip to tip, and with an upward curve due to the currents of heated air. In attempting to photograph such an arc, it was found necessary to shield the lens from the strong violet rays of the arc proper, in order that sufficient exposure might be obtained on the wings. The ends of the carbons, as shown by the photograph, although brilliantly incandescent, do not appear to give out many chemical rays. A short exposure was made to suit the violet arc, and the result indicated that but little violet light was given out by the incandescent ends. The question, therefore, arises, is not the curve of illumination for actinic rays for any arc lamp quite different from the curve of illumination for visual rays? Graphic illustrations of the current curve, both before and after separation by magnet, are shown in Bedell's article.

Carbons and Methods of Arrangement.—As has been indicated in previous pages there are two classes of carbons used in arc lighting, viz., solid and cored. Their diameter varies according to the voltage and the current consumed.

For those in general use, the average resistance is 0.15 ohm per foot.

Solid Carbons.—These vary according to their purity, molecular structure and hardness. The best are known as the electra or Nuremberg carbons, and are manufactured in Germany.[1] The electra of domestic manufacture are not comparable to the Nuremberg carbons as to purity and hardness. The former resemble graphite in these respects. Carbons are very apt to be filled with impurities, all of which prevent the securing a true carbon spectrum. There may be an increase of the frequencies of one or another portion of the spectrum, by reason of such impurities. If impregnated with iron pyrites, for example, there will be an increase in the ultra-violet frequencies, which is not objectionable for considerable therapeutic work. Where iron is used, however, it is better it should be pure. Sodium, on the other hand, would give an increase in yellow.

Cored Carbons.—These are solid save for a hole which runs axially through the length of the carbon. This hole is filled with some material softer and more readily volatilized than the remaining carbon. Usually, it is a mixture of carbon and some metallic salt. The object of this core in illumination is twofold: (1) to decrease the voltage for a given length of an arc, or (2) to increase the length of an arc for a given voltage. Initially, this has the effect of reducing any irregularity in carbons or the feeding mechanism to a less percentage of the whole length. In addition, the core, by affording a plentiful supply of vapor, tends to maintain a stable condition of the arc. By the use of a cored carbon, the tendency is for the arc to remain located in one spot, i.e., at the core, instead of travelling in an irregular fashion all over and around the end of the carbon in an effort to establish the way of least resistance. The core does that, and thereby maintains a steady non-fluctuating arc. The core of a carbon may also be used for the pur-

[1] Imported by Hugo Reisinger, 71 Broadway, New York City.

pose of intensifying certain portions of the spectrum. This is very important in therapeutics where it is desired to increase the number of the highest chemical frequencies or ultra-violet rates of vibration. For this purpose carbons cored with iron are of great service. The ones manufactured in this country are inferior to those imported. The Nuremberg carbons are prepared with powdered iron incorporated into the mass which forms the core. When similar carbons are placed vertically one over the other, their relative consumption depends upon the amount carried off by: (1) volatilization and electrolytic action; (2) oxidation of the air; and (3) mechanical disintegration by air currents. Putting aside the oxidation of the air, the life of carbons of different diameters increases in proportion to their sectional area. To increase the conductivity of the carbons they are sometimes plated for about nine-tenths of their cylindrical surface with a thin layer of copper, the tip only being left uncoated. The primary object of the plating is to reduce the contact resistance of the carbons. A copper-plated carbon would secure to the spectrum the rates of vibration of copper in addition to that of carbon. Few of the copper lines are sharply defined, even on one side, and the spectrum, therefore, has a peculiar appearance. In the Bunsen flame cupric chloride produces a band spectrum extending over the whole field with the exception of the violet; the same spectrum is obtained with the metal if the flame contains hydrogen chloride. The absorption spectra of copper salts are not characteristic, as the compounds produce total extinction both in the red and violet. The addition of copper has no advantage therapeutically.

With the use of heavier currents from 50 ampères upwards, the carbons become hotter and are oxidized farther back from the ends, and, therefore, have longer points. Inside of the crater, the positive carbon wastes away by electrolytic action, and outside of the crater by the action of the air upon it. This wasting in an open arc is twice as fast for the positive as the negative. The consumption of the

negative is due to the oxidization of the air alone, according as its temperature is increased by the carbon particles deposited on it, and by the heat reverberated from the crater. The shorter the arc, or the closer the positive to the negative, the greater will be its heating effect upon it. In very short arcs the deposit of the particles of molten carbon or graphite is greater than with long arcs, so much so that the negative accumulates faster than it wastes away, and a nib or second point is formed on the negative which finally crumbles away. In the long arc these particles of boiling carbon float about and serve to reflect and refract the rays of light, thereby increasing, as has been pointed out, the violet and ultra-violet frequencies. Carbon that has been exposed to the temperature of the arc is turned to graphite. The tip of a negative will write as will a pencil, and the positive also shows some graphite.

The Arrangement of the Carbons of Arc-Light Mechanisms and Reasons Therefor.—The arc mechanism may be arranged with the electrodes in a perpendicular or vertical position, horizontally or at an angle varying from an obtuse to a right angle. In vertical arcs, the positive carbon is usually the upper one. The reason for this lies in the fact that the crater formed in the positive carbon by the volatilization of the carbon is the source of the most intense light, and by placing the positive carbon above, the light is thrown down. This is as a rule desirable for purposes of illumination. If it is desired to illuminate the space above rather than below the arc, the position of the carbons is reversed. In a horizontal arc, as in a marine searchlight, for example, where a Mangin mirror or reflector is placed at the back of the arc, the positive carbon is placed in front of the negative, thus directing the arc toward the reflector and away from the object upon which the illumination is to fall. The reason for this is that all the emerging rays shall be parallel, in which condition their intensity is theoretically the same at any distance, but practically not, owing to unavoidable dispersion, due to the size

of the light-emitting surface, aberration in the reflector, and the refraction and absorption of the atmosphere. With the crater turned toward the front of the searchlight, all of its rays that did not strike the reflector would be divergent instead of parallel.The carbons in searchlights, as in projector lanterns, locomotive headlights, may also be inclined at an angle varying from an obtuse to a right angle. When the carbons are inclined away from an object so that the maximum rays at an angle of about 45°, from the axis of the positive carbon will be directed nearly horizontally at the point to be illuminated. This method is used, as will be seen in discussing apparatus and arrangement of mechanisms for therapeutic work. Besides being tilted the upper carbon is often set back somewhat out of line with the negative, which brings the crater at an angle without tilting the carbons. Arc-lamp mechanisms so arranged are very difficult to feed automatically and therefore are apt to be hand-fed lamps. In the various arc-light mechanisms in use for therapeutic work, the arrangement of the carbons differs. In the lamp used in the Finsen Light Institute at Copenhagen, with the Finsen tube, the carbons are arranged vertically and the tube, with its condensing lenses of quartz, is placed radially to this powerful arc, so that the light from the *arc* impinges upon the lens at the proximal end at an angle of about 45°. The well-known London Hospital lamp, originally the Lortet-et-Genoud lamp, has the carbons inclined at an angle of about 45°. This is theoretically the best position of the carbons, for the reason that the energies of the *light of the arc* proper, the vapor light, or violet mist is brought more directly opposite the quartz lens of the water-cooling chamber and is therefore carried more directly to the patient. In a vertical arc, the carbons may be "staggered" or the upper one set back somewhat out of line with the negative, as indicated, which brings the crater at an angle the same as when the carbons are placed at an angle, and renders it possible to utilize the light of the *arc* proper at its full value. The

objection to this position of the arc in therapeutic work is the necessity of using a hand-fed instead of an automatically fed mechanism. In the small iron electrode lamps, the electrodes are placed vertically. The construction of these mechanisms is such as to preclude any different position of the contacts.

Regulators of the Electric Arc.—For therapeutic work, as well as for the purpose of illumination, it is necessary that the light must be continuous. To this end it is not only essential that the current should be constant, but that the distance of the carbons must not alter. Therefore it is necessary to use some arrangement by which they may be brought together in proportion as they wear away. Two methods are used for this purpose: (1) hand regulators and (2) automatic regulators. The first is an arrangement of a screw, to be adjusted by hand and which regulates the position of the carbons in relation to one another as they are worn away. For therapeutic work this is unquestionably the most delicate method, but possibly necessitates more careful attention on the part of the operator than the second or automatic-fed mechanism.

Automatic Regulators.—There are two distinct classes of mechanisms employed in arc lamps: (1) those which maintain constant the distance between the electrodes, but do not keep the position of the arc fixed, and (2) those which not only keep the distance between the carbons fixed, but which also maintain fixed the position of the arc.[1]

In the first class of mechanisms but one carbon usually the upper or positive carbon is fed or moved; in the other class, both carbons are moved and in this case since the positive is consumed more rapidly than the negative the relative motions of the two carbons must be different. To the first class of mechanisms belong the ordinary type of arc lamps employed for street lighting. These same arc-light mechanisms are used therapeutically in arc-light cabinets.

[1]Houston and Kennelly, Electric Arc Lighting.

To the second class belong various projectors, searchlights or other apparatus employing reflectors or lenses. In the latter instance it is necessary that the arc shall be maintained at the focus of the reflector or lens. This is the case with the marine searchlight mechanism in use for therapeutic work. The feeding mechanism then in any form of arc lamp, in order to insure continuous operation must comply with the following 3 conditions: (1) It must bring the carbons initially into contact. (2) It must then separate the carbons to a suitable distance and maintain this distance. (3) It must cause or permit the carbons to approach when consumption or burning has rendered their separating distance too great.

There have been many arc-light mechanisms devised, and there are many in extended use. While they present minor differences, fundamentally they are practically the same, for all lamps suitable for series connections; that is to say, an electro-magnet in the main surface operates a mechanism which effects the separation of the carbons, while another electro-magnet placed in the shunt circuit, effects an approach of the carbons.

The Gases of the Electric Arc.—With a powerful current a very dull incandescence is observed, accompanied by a bluish lambent flame, over the ends of the carbon electrodes when the gap is from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in length. The origin of this flame is exactly the same as that which may be observed playing over a hard-coal fire, when by reason of an insufficient supply of air it has not reached full incandescence. This is due to the burning of the carbon vapor in the oxygen of the surrounding air. Chemically, carbon undergoes two distinct forms of oxidation, producing carbon monoxide, as in the case of the hard-coal fire, and also the ends of the carbon in the electric arc; and a second but more complete oxidation, carbon dioxide or carbonic acid. It is believed that in the interior of the arc no oxidation of carbon vapor occurs, not only because the vapor fills this interior space,

and, therefore, displaces the air, but because the temperature of the disengaged vapor is so high that it is above that at which carbon monoxide can exist, without *dissociation* or separation into carbon and oxygen.[1] The inner portion of the arc stream which consists of a violet hub of incandescent carbon vapor, is surrounded by a thin non-luminous portion where the combination of the carbon with the oxygen of the atmosphere in dark flame takes place to form carbon monoxide (CO). As the temperature is above that at which the monoxide of carbon can exist without dissociation into carbon and oxygen, it follows that there is such a dissociation or separation and the oxygen thus released is, in turn, enveloped by a layer of luminous flame in which the carbon monoxide burns to carbon dioxide (CO_2). Besides this combination there is an action on the nitrogen of the air by oxygen set free and uncombined forming an oxide of nitrogen. From the characteristic odor as well as from the powerful deodorizing or disinfecting nature of the arc when in activity, it has been supposed that ozone was given off to some extent during the activity of the arc. This is not the case. The odor is attributed to the presence of small quantities of hydrocyanic acid gas. None of these gases are given off in sufficient quantities where the voltage of the arc does not rise above 55 in air to be injurious. On the contrary, judging from clinical results they would seem to be helpful, for as will be shown in the use of the arc therapeutically, voltage 45, two in series 15 ampères each, there is evidence of an immediate oxidizing action upon the respiratory mucous membranes, when patients with bronchial asthma, bronchitis, tuberculosis pulmonalis or catarrhal colds are exposed to their activities. So true is this that the author has for the past 11 years used an electric-arc cabinet, constructed in such a way as to permit the patient to lie fully within it, head as well as body, with excellent results. Whether there is an

[1]Houston and Kennelly, Electric Arc Lighting, pp. 21-24.

anæsthetic effect produced upon the mucous membranes by the action of carbon dioxide is an open question. The relief from cough is established at the first exposure and persists with the continuance of the treatment at successive periods of time, nor is there ever any indication of any irritating or untoward effect upon the mucous membranes.

The production of the oxides of nitrogen in air by an active arc has been fully established by Charles S. Bradley,[1] both by experimental work and successful practical application of the principle, to the commercial production of atmospheric products. This is justification for the belief that the outcome of all the combinations and recombinations which take place during the burning of the arc is the formation of oxides of nitrogen in the air. The same is true of the disruptive discharge from a static machine or a high tension coil, but with that there is also a production of ozone while the brush discharge produces ozone and no oxides of nitrogen. Therefore, if it is desired to produce ozone the brush or convective discharge is efficient, if oxides of nitrogen, the electric arc, while the disruptive discharge is unsuitable for the one or the other. If it be true that there is a momentary production of ozone (due to liberation of oxygen molecules, which temporarily unite with O_2) at the breaking of an arc, i.e., when the physical conditions of the arc correspond to the condition of strain in the air, before the actual lightning discharge, there is then a reason for the belief that there is more ozone produced by an alternating-current arc than by a direct one, for by reason of the alternations there is a constant breaking of the arc.

Negative Corpuscles, Carriers of Negative Electricity from Incandescent Metals and Carbon, their Relation to the Arc Discharge.—From incandescent metals and carbon there is a very rapid escape of negative electricity. J. J. Thomson[2]

[1]Personal communication.

[2]J. J. Thomson: Conduction of Electricity through Gases, pp. 164, 165.

in his investigations on the conduction of electricity through gases, shows that this electrification from a hot wire is conveyed by the same carriers as the cathode rays, i.e., by "corpuscles," "those small negatively electrified bodies which in all of the phenomena investigated by him, were found to act as carriers of negative electricity in high vacua."

"Corpuscles" are projected, according to his theory, from an incandescent metal or glowing piece of carbon, the rate of emission being very much greater with a carbon than with a platinum filament, amounting in the former when it is at its highest point of incandescence, to a current equal to several ampères per square centimetre of surface. In like fashion the sun and, probably, any luminous star is to be regarded as a source of negatively electrified particles, which stream through the solar and stellar systems. When corpuscles moving at a high speed pass through gas, they make it luminous. In the same fashion when the corpuscles from the sun meet the upper region of the earth's atmosphere, luminous effects are produced. These corpuscles are disseminated through metals and carbon, not merely when they are incandescent, but at all temperatures; they are so small that they are able to move freely through the metal, and may thus be supposed to behave like a perfect gas contained in a volume equal to that of the metal. The corpuscles are attracted by the metal, so that to enable them to escape into the space surrounding it they must have sufficient kinetic energy to carry them through the layer at its surface, where its attraction of the corpuscles is appreciated.

If the average kinetic energy of a corpuscle, like that of the molecule of a gas, is proportional to the absolute temperature, then as the temperature increases, more and more of the corpuscles will be able to escape from the metal into the air outside.

The phenomena connected with the discharge of electricity from incandescent bodies Thomson[1] found to indi-

[1]J. J. Thomson: Conduction of Electricity through Gases, pp. 424, 425.

cate a different explanation of the arc discharge. An incandescent body, such as a piece of carbon, even when at a temperature far below that of the terminals in the arc, discharges, as has been stated, negatively electrified corpuscles at a rate corresponding to a current of the order of an ampère per square centimetre of hot surface. If a piece of carbon were maintained independently at the same high temperature and used as the negative electrode, a current could be sent through the gas to another electrode, whether this second electrode were hot or not. Suppose the anode to be cold, then the current would be entirely carried by negative ions, these would cause the electric force to increase as we pass from the cathode to the anode resulting in a rapid increase of current with the potential difference. If the anode then becomes hot and has some gas in contact with it which can be ionized, yielding a supply of positive ions, the current will no longer be carried entirely by negative ions, though inasmuch as the velocity of the negative ion at these high temperatures is very much greater than that of the positive, by far the larger part of the current is carried by the negative ions. The distribution of potential between the electrodes is very much modified, however, by the presence of the positive ions. The latter diffuse into the region of the discharge until they are sensibly equal in number to the negative ions; when this is the case there is a very uniform electric force between the terminals, except close to the electrodes. The distribution of potential between two hot electrodes bears a great resemblance to the distribution of potential between the terminals in the arc discharge. By the high temperature in the interior of the metal, an electric force is produced which drives the electrons toward the anode.

It is believed by Thomson that the arc discharge is similar to the discharge between two incandescent terminals, the only difference being that in the flame the temperature of the terminals is maintained by independent means while in the arc it is maintained by the work done by the discharge

itself, which requires that the potential difference between the electrodes also the current passing should not sink below certain values. On the other hand maintaining the temperature by external air, the smallest potential difference is required to send a current.

Regarding the arc discharge from this point of view then, the cathode is bombarded by the positive ions, which maintains its temperature at such a high value that negative corpuscles come out of the cathode. The anode is bombarded by these negative corpuscles which carry by far the larger part of the arc discharge and is thus kept incandescent. They also ionize either directly by collision or indirectly by heating the anode, the gas or vapor of the metal of which the anode is made, producing in this way the supply of positive ions which serve to keep the anode hot. The essential thing in the arc discharge is the hot cathode as it has to supply the carriers, negative corpuscles, of the greater part of the current in the arc. As the metal or the carbon terminal of an arc volatilizes, the arc goes through a mixture of the vapor of the metal and the air. The negative corpuscles of Thomson serve to produce on ionization of this gas or vapor and of the air itself, a condition which to the author's mind is comparable to the action of the negative corpuscles emitted by the glowing carbon of the photosphere of the sun upon its gaseous envelope.

The arc is deflected by a magnetic field in the same direction as a flexible conductor would be if it carried a current flowing in the same direction as that through the arc.

The curved course corresponds to a longer path and the effect of the magnetic field on the potential difference is of the same character as an increase in the length of the arc, and just as it is possible to extinguish an arc by increasing its length, so the arc can be blown by the application of a strong magnetic field.[1]

The ionic theory of the electric arc has been investigated

[1]Thomson, p. 431.

to a considerable extent by Stark.[1] In order to make the matter more simple he began his investigations with the mercury arc which is longer than the carbon. Four distinct parts are distinguished, viz: (1) The brilliant brush issuing from the white hot depression in the cathode, (2) the dark space, (3) the positive light column and (4) the anode layer. The arc light involves the evaporation of the cathode or negative carbon as has been stated, but this is not necessarily involved by the glow discharge. Nor is it essential that the anode should emit vapor, as is the case in the carbon arc.

In all gaseous discharges, electrons, positive atomic ions, and molar ions have to be distinguished.

Negative electrons play a very important part in a Bunsen flame. They are even more predominant in the higher temperature of the electric arc, as is shown by the susceptibility of the arc to magnetic deflection and the readiness with which it follows every variation in the current. This is owing to the great nobility of the electrodes. The impact of the electrons produces positive and negative ions from neutral molecules at the anode and in the positive light. In the glow discharge the phenomena are reversed, whereas in the arc the negative electrons are produced from the cathode by electrification, and not from the gas by ionization. The presence of ultra-violet light, but most of all the high temperature of the cathode, favors the ejection of electrons from the interior of the cathode.

The anode on the other hand must be hot, otherwise it could not supply the positive ions which keep the cathode hot. If a third electrode were put in the arc acting as one of the anodes, then the discharge may be regarded as having two anodes. As one is sufficient to keep the cathode hot, the arc can pass to the other anode even although it is cold. A small portable lamp, with iron electrodes for therapeutic work, is constructed on this principle, and is known as the Reiniger, Gebbert and Schall lamp.

[1]Am. der Physik No. 12; London Elect., Dec. 4, 1903; Electrical World and Engineer, January 2, 1904.

The negative corpuscles, therefore, play an important part in the activity of the arc, acting (1) by carrying the arc discharge, (2) bombarding the anode to incandescence, (3) ionizing directly by collision, or indirectly by heating the anode, the gas or the vapor of the metal, of which the anode is formed, producing in this way (4) the positive ions, which serve to keep the cathode hot.

Metallic oxides project more electrons at high temperatures, and hence the arc, which requires a liberal supply of electrons is more easily formed of the oxide than of the pure metal.

The negative electrons, given off at different rates, evidently for different metals, influence the potential difference.[1]

Of the constants m and n in Fröhlich's formula, as measured by Fröhlich himself and Edlund, Lang,[2] Gross, and Shepard, Nebel, Arons,[3] Luggin for carbon electrodes in air at atmospheric pressure, m is about 39 volts, varying somewhat, however, with the size and purity of the carbons. It is diminished by soaking these in salt solution. The value of n, as given by different experimenters, varies considerably. This may and probably is due to their having used currents of different intensities, as Mrs. Aryton has shown that n depends upon the current, for as the current increases, n or the potential difference diminishes. When metallic, instead of carbon terminals are used the value of n or the potential difference depends upon the metal. As a rule this is greater the higher the temperature at which the metal volatilizes. The following table gives the value of the potential difference in volts for different substances:[4]

[1]Thomson, J. J. Conduction of Electricity through Gases.
[2]Lang: Wied. Am. XXXI., p. 384, 1887.
[3]Arons: Wied. Am., p. B, 1896.
[4]Thomson.

$C = 35$, $Pt = 27.4$, $Fe = 25$, $Ni = 26.18$,
$Cu = 23.86$, $Ag = 15.23$, $Zu = 19.86$, $Cd = 10.28$.

Lecher[1] gives $Pt = 28$, $Fe = 20$, $Ag = 8$. Arons found that but 12.8 volts were required for Ag, but in this case the fall of potential along the arc itself was very small. With some of these metals used as terminals the arc is intermittent. Iron, platinum and mercury have been shown to give an intermittent arc, while no intermittence has been detected with carbon, silver and copper terminals.

These potential differences with arcs of different metals are mean values, and if the arc is intermittent they may differ greatly from the actual potentials during the passage of the arc. When the different metals are used for the two terminals, the potential difference may depend upon the direction of the currents. This is especially true when one of the terminals is carbon and the other metal, carbon and iron for example, or an iron-cored carbon. The arc passes much more readily when the carbon is the negative terminal, and the metal the positive one than it does in the opposite direction. So true is this that if such a pair of terminals were connected up with an alternating potential difference, the arc may only pass in the direction in which the carbon is the negative terminal, the potential difference being insufficient to drive it the opposite way. Some metals again are non-arcing metals; that is, they have a tendency to go out, such as brass, bismuth and cadmium. A great deal depends upon the size and shape of the electrodes, as well as the material of which they are made. Conditions which promote a rapid flow of heat from the extremities are favorable to the extinction of the arc.

The potential difference depends also upon the pressure of the gas through which the arc passes. Duncan, Rowland and Todd have shown that for short arcs the potential difference increases continuously with the pressure, while for longer arcs there is a critical pressure at which the potential

[1]Lecher: Wied. Am. XXXIII., p. 609, 1888.

difference is a minimum; this critical pressure increases with the length of the arc. The arc is affected by the nature of the gas; in hydrogen, for example, it is difficult to get a good arc, and this is supposed to be due in part to the more rapid convection of the heat from the terminals.

The potential difference required to produce an arc by the use of different metals, both in air and pure nitrogen, has been measured by Arons.[1] In the case of silver, while giving a good arc in air, none could be obtained in pure nitrogen. This Arons attributed to the absence of any chemical combination between the silver and the nitrogen. With the other metals used, zinc, cadmium, copper, iron, platinum, aluminum, lead, and magnesium, he obtained evidence of the formation of nitrites. Copper excepted, the potential differences in nitrogen are smaller than in air, the difference being very noticeable in the cases of iron and aluminum. In both these instances *more active ionization* of the air, due to their temperature of volatilization, rates of oscillation and electrons given off, the noticeable difference of potential between these two in air and nitrogen (smaller in nitrogen than in air) is to be accounted for. This is not yet clearly established.

Arons was only able to obtain arcs in hydrogen by using large currents and having the gas at low pressure. Cadmium, zinc and magnesium gave the best arcs in hydrogen.

As the metal or the carbon terminal of an arc volatilizes, the *arc* goes through a mixture of the vapor of the metal and the air, or in the experiments referred to, nitrogen or hydrogen, in which the terminals are immersed. This renders it difficult to interpret the effect of changes of pressure in the gas around the terminals, as the pressure of the vapor of the volatilizing metal is not known.

It has long been known that air in the vicinity of red hot metals is a conductor of electricity, nearly two centuries in fact.

[1]Arons. Drudes' Annalen, I., p. 700, 1900. Quoted from Thomson's Conduction of Electricity through Gases.

In 1853 Becquerel[1] showed that air at a white heat permitted the passage of electricity even when the potential difference was only a few volts. This result was confirmed by Blondlot[2] whose observations went still further, for he proved that air at a bright red heat was unable to insulate under a difference of potential as low as 1/1000 of a volt and that conduction through the hot gas was not in accordance with Ohm's law.

Attention was first called by Guthrie[3] to a very characteristic feature of ionization by incandescent metals, viz., the want of symmetry between the effects of positive and negative electrification. He showed that a red hot iron ball in air could retain a charge of negative, but not of positive electrification, while a white hot ball could not retain a charge of either positive or negative electrification.

The Electric Arc a Disinfectant.—An electric arc in operation serves as a powerful disinfectant.

The action of the energy of the electric arc spectra upon bacteria has been very fully considered, but it would seem that there is an effect produced more immediately than would follow upon the destructive action of the short and high frequencies so active chemically upon bacterial growths.

Experiments were made many years since with the Jablochkoff candles in the Paris sewers for the purpose of purifying them. The results were very satisfactory.

In 1881 Mr. Harold P. Brown, E. E.,[4] of New York, while using Brush arc lamps for lighting the basement of a store in Chicago, noted that within an hour after turning on the current, the odor from the *toilets* which was at first very offensive became entirely neutralized.

On an excessively hot day the author made the following observation; the refuse barrels which had accumulated

[1]Becquerel: Annales de Chime et de Physique, III., 39, p. 355, 1853.

[2]Blondlot: Comptes Rendus, XCII., p. 870, 1881; CIV., p. 283, 1887.

[3]Guthrie: Phil. Mag. IV., 446, p. 257, 1873. Quoted by J. J. Thomson.

[4]Personal communication.

in the basement of the apartment house occupied as an office over Sunday, prior to their removal Monday morning emitted a very unpleasant odor, which ascended and permeated the office rooms occupied by the electric-arc cabinet as well as rooms to the rear of it. The current operating the electric arc was turned on and in half an hour the author returned to the room, to find that every evidence of odor had disappeared and that the air was perfectly pure, so far as odor was concerned, while in the rooms more remote from the arc, the odor persisted as before. The action was at that time attributed to the ozone generated and unquestionably it is a factor. There is the nitrous oxide to be reckoned with as well, but the effect in all probability is due to an ionization of the air. Since then, if for any reason there has been the slightest odor in the offices the current has been turned on the arc lamp and always with the same result.

The Mercury Vapor Lamp.

The temperature inside of the lamp, which depends upon the current, diameter and density of the vapor, is not ordinarily very high—a few hundred degrees Centigrade at the most.

The most striking feature of the lamp upon casual examination, is the color of the light which it emits. This, to be appreciated, must be seen as it is difficult of description. It is spoken of as having a yellowish-bluish green color, the nearest approach to naming the color. It suggests to the author an opalescent coloring. Spectroscopic examination shows the presence of two somewhat faint orange lines, two very bright green lines, two bright blue lines, and two faint violet lines. There are no red lines present and therefore it is impossible for the lamp to give off white light, as red is a necessary constituent of white light. From the orange, green, blue and violet present, results the characteristic coloring. Objects which ordinarily reflect red light, like the human being, for example, suffer a very remarkable and gruesome color distortion. The appearance is ghastly in the

extreme, but is overcome by the use of a specially prepared red or pinkish gauze which is thrown over the lamp as a scarf or drapery. This supplies the red frequencies and by reason of its preparatory chemical treatment functions as a radiant frequency transformer. A tube of red glass would permit no light to emerge whatever, for red glass transmits red light only and there is no red light to transmit. The light is extremely rich in ultra-violet waves, richer even than the arc light, but by reason of the glass of the vacuum tube there is no possibility of their emergence. It is very rich, however, in the visible chemical frequencies, and for this reason and also because of its diffusion, it is very valuable in photographic work. Its efficiency is estimated at from two to three times that of the arc light and from six to eight times that of the incandescent light. It consumes less current than the incandescent light.

It is impractical for applications where compression is desired to render a part anæmic. These lamps could be suspended around the walls of a large enclosing cabinet or room for general uses, but the author is not prepared to state that it would be well to use them in preference to the other sources of light if at all. They lack the radiance that renders sunlight, the electric arc, incandescent light even, so acceptable to the anæmic, neurasthenic or tubercular patient as well as of such therapeutic value. Rich as they are in ultra-violet light, it is of no value for less than 30 microcentimetres because of the glass enclosing tube. Objections have been raised because of the mercury vapor but the author fails to see how with this enclosed in a vacuum tube of glass it can possibly have any effect. Were it a quartz enclosing tube the ultra-violet would be powerfully in evidence and the result from exposure to so powerful a source of concentrated ultra-violet energy might be productive of untoward results. The author has had one of these lamps placed at her disposal during the past year but from observations thus far made, would not select it as a source of radiant light energy for therapeutic work. It can only be stated here as

an impression received from observations, not supported as yet by experimental data, that the absence of the red and the diminution in the orange and yellow, in other words, of those factors which give the sensation of radiance, is one for which its powerful chemical action cannot compensate.

There is in relation to physiological action and therapeutic uses of light a need for these long and slow frequencies—although in the present state of the biological action of light it is not known just what their mode of action is. Function they undoubtedly have. It only remains to be elucidated. Were the enclosing tube of such size and shape as to render it suitable for topical applications, the richness of the light chemically could be availed of.

The following data and the description of the test to determine its candle-power were furnished by Professor Sheldon of the Brooklyn Polytechnic Institute, in connection with the author's committee work on "Radiant Energy" for the American Electro-Therapeutic Association.

Data Concerning the Cooper-Hewitt Mercury Vapor Lamps.—An effort was made to determine the candle-power of this lamp by making use of an observer who was afflicted with color-blindness. His visual characteristics are shown by the following facts: He called a bright red glass green, and was very positive concerning it. He called a green glass brown or red and was not very certain. Blue he termed blue, amber was called a light red. A bright red was again called brown and he matched a bright red against a muddy purple as being alike.

The prominent lines of the mercury spectrum appeared to him as follows: The two orange lines as dark yellow, the faint green he could not see, the purple of long wave length he considered not as light as Columbia blue, but as blue, and the violet of shorter wave length he termed as the same color which could be purchased at a florist's. It will thus be seen that he is what may be termed red and green color blind. When used as a photo-metric observer in balancing two incandescent lamps against each other, both burning

at the same temperature, making use of a *Lummer Brodhun* screen he made settings which were practically identical with those of ordinary observers.

When balancing the light from an aperture 10×2 centimetres placed in front of the vapor lamp against the standard 16 candle-power lamp he was unable to obtain a definite point of balance because of the different color qualities, but at a place where the corn yellow exhibits to the ordinary observer about the same depth as the sky blue, these colors changed suddenly to the eyes, the yellow appearing yellow, but the blue assuming a color he had never seen before.

By holding the green glass in front of his eyes he made very precise balance setting, which yielded the following results: Through the 20-centimetre-square opening passed luminous flux such as would come from 63.5 candle-power sources of 3.18 candle-power per square centimetre. The lamp was taking 3 ampères at 73 volts, exclusive of the starting rheostat.

Assuming a uniform distribution of light emanations, the tube which is 114 centimetres long, and of approximately 2.4 centimetres internal diameter, will give 870 candle-power.

It has been suggested that its value in medicine will be as a diagnostic agent chiefly.

As there are no red frequencies any red spot on the body of a person subjected to its action or any red object observed becomes a deep purple.

Therefore any mild inflammation or rash, either faint or more distinct, will become under its influence a distinct purple in appearance and an eruptive disease may be detected earlier and more clearly than would otherwise be possible.

The accompanying illustrations show the energy curve of different sources of light. The author is indebted to the courtesy of Professor Langley of the Smithsonian Institute for their use. (See Figs. 2 and 3.)

The second plate is introduced as showing the amount of energy wasted in sunlight, when considered as a luminous

Four Curves of Equal Areas, showing one unit of heat displayed successively in heat spectrum of Gas, Electric Arc, Sun and Fire-Fly.

ABSCISSAE.—WAVE LENGTHS.
ORDINATES.—ENERGY AS HEAT.

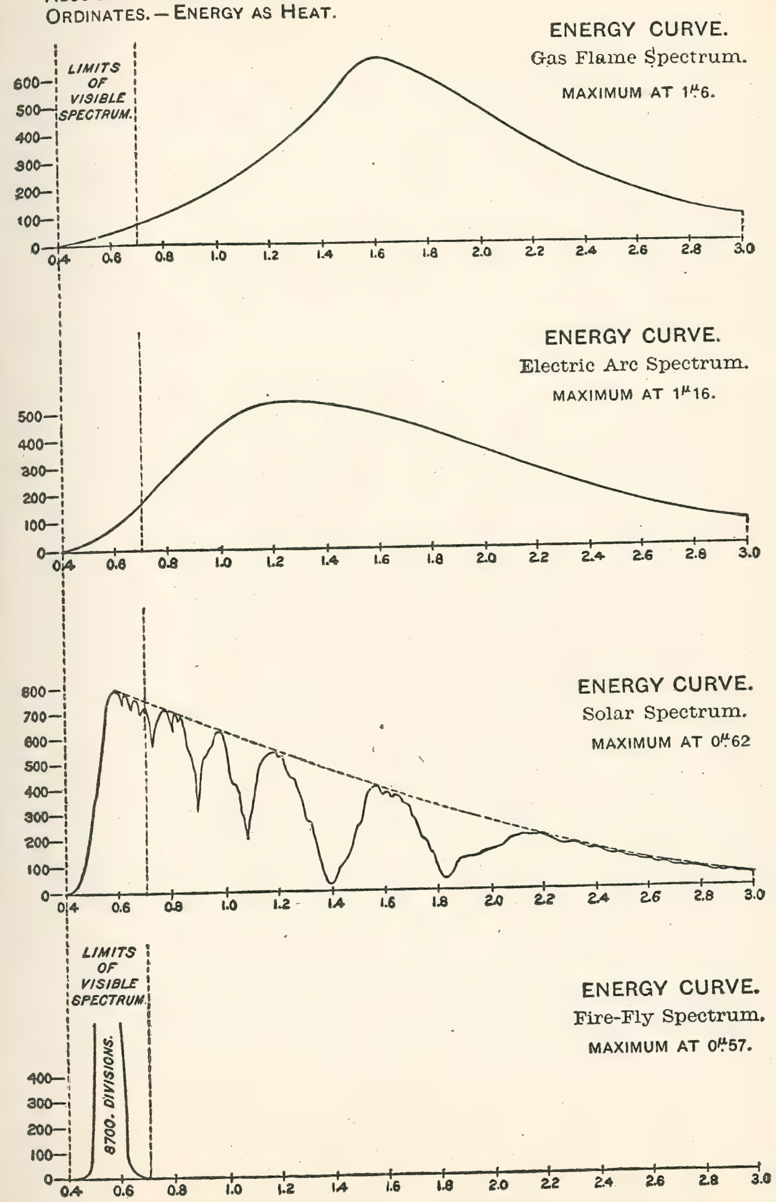
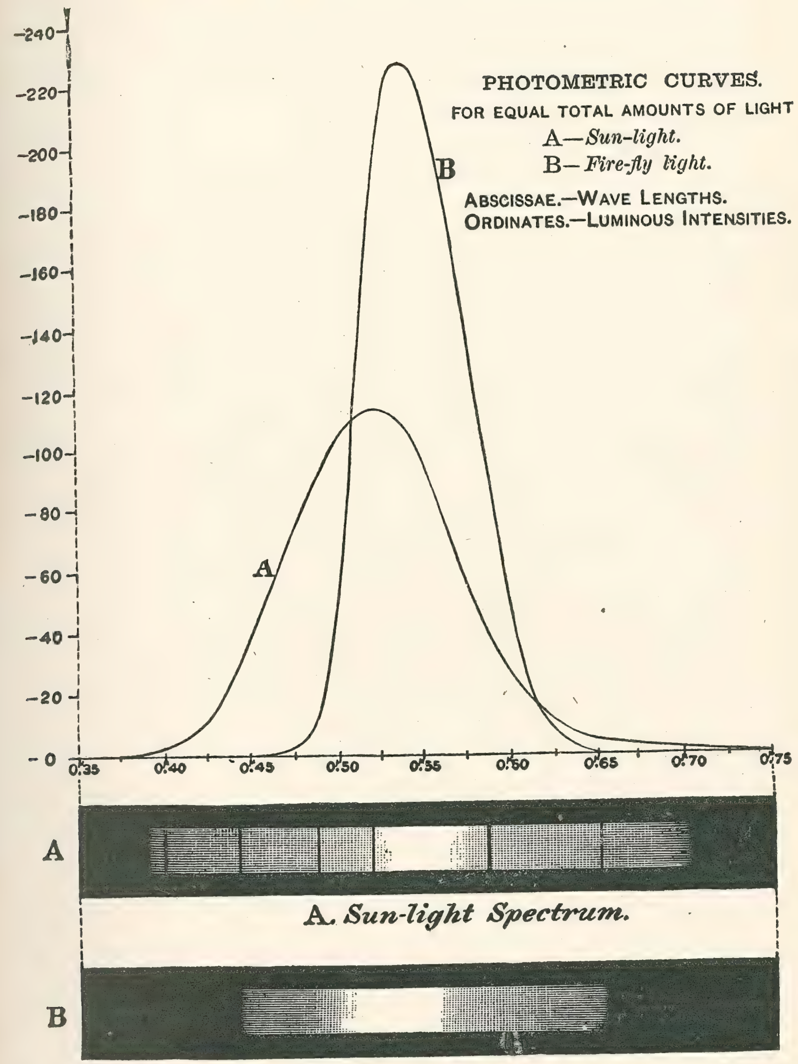


Fig. 2.



A. *Sun-light Spectrum.*

B. *Fire-fly Spectrum.*

Fig. 3.

agent only, illustrating at the same time the luminous efficiency of the firefly spectrum. But as these pages endeavor to show, the sun shines not simply for the purpose of illuminating the darkness, but that life from the elementary forms to the higher organisms may exist.

CHAPTER III.

The Action of Light Energy upon Elementary Forms of Life.

The irritability of a mass of protoplasm of a protozoan of the simplest kind is established in a certain manner under the influence of light energy. This has been extensively studied.

Action of Luminous Rays upon a Plastide.—If a beam of parallel luminous rays of feeble intensity fall upon a plastide in water, the reactions between the plastide and the surrounding medium are favored by the energy delivered in this way. This was studied by Dantic.[1] Chemical reactions are established which are much more active on the surface upon which the light falls than on the opposite face, but feebly illuminated by the light filtered through the mass of protoplasm. The plastide is divided into two parts, so to speak, which are respectively the seat of excitations of different intensity. The result of this difference is shown by a direct action whose beginning and direction can be calculated by mathematical analysis, for a body of determined form.

Phototaxy Positive and Negative.—This theoretical fact is verified by a quantity of experimentation done by Strassburger, Verworn, Engelmann, etc., bearing upon *plastides,* diatoms, spores of algæ, bacteria.

[1]F. Le Dantic: Materie Virante, Paris. Mosson quoted by Leredde and Pautrier.

The movements vary in direction and the minute mass of protoplasm can be drawn out or retracted under the influence of a beam of light. In the first instance it is positively phototaxic, and in the second negatively phototaxic. On the other hand, there are certain plastides that are not influenced by light, that is, they are not phototaxic. This latter condition may, however, be dependent upon the degree of light intensity to which it is subjected. If the intensity is too feeble it may appear to be non-phototaxic when such is really not the case.

Leredde and Pautrier pertinently remarked that the intensity should always be given when positive or negative phototaxic conditions are considered. For example, an amœba which will stretch out or contract its protoplasm under the influence of feeble light intensity will contract itself sharply if the intensity is increased.

In the absence of all phototaxic phenomena it is difficult to establish whether or not the protoplasm under consideration did not react because the light was too feeble. However, all protoplasm can be considered as phototaxic, either positively or negatively.

If an infusion containing various plastides be exposed to diffused light, certain among them will be seen to gather themselves into the brightest part, while others will remain in the shade.

It is in this way that Engelmann takes in a trap bacteria in a bright spot from a liquid kept in the dark. From a close study of this phenomenon it will be seen that it is not only the passage of light in obscurity which exercises an excito motor action upon protoplasm, but also difference of light intensity. Purple bacteria are particularly sensitive to this mode of action. If the intensity of the light illuminating the preparation be diminished, when examining them, the rotation of their bodies is reversed and they extend abruptly to a distance equal to ten or twelve times their length. Any spot thus illumined in a tube or receptacle containing the bacteria, becomes a veritable trap for them. They

readily enter the brightest spot which attracts them, but it is impossible for them to leave it, for in passing into the dark peripheric zone, they are sharply thrown back into the bright zone, just as iron filings are brought into relation with a magnet, for example.

In his experiments Engelmann illuminated the centre of the drop of water, upon which he was operating, then fixed and colored the mass of bacteria which had quickly assembled there. He obtained in this way what he calls a bacteriogramme. In this way he preserved the image of the space in which the bacteria were caught in a trap.

The excito motor action of light is very clearly shown on purple bacteria. They are one of the best examples, and are sensitive to the luminous excitant alone. Upon illumination they take on a state of continual motion or, as termed by Leredde and Pautrier, a period of photokinetic induction When the light is removed they return to a state of complete repose.

Among the miscellaneous algæ positive phototaxy is equally frequent.

In his study of the movements of diatoms Engelmann[1] shows the cessation of movement when he placed them in the dark sheltered from oxygen and recovery of the same with light.

This phenomenon is complex, for it is not alone the presence of light, but it is also due to the consumption of oxygen, which they are unable to appropriate in darkness. In the light on the other hand the decomposition of the ambient CO_2 by their coloring matter furnished them at the same time with the assimilable C, the oxygen necessary to their movements.

It was observed in the closteria, a unicellular alga, of the group of *desmidia,* fringed at both extremities that when placed in a crystal receptacle upon which the beam of

[1]Pflüger's Arch. Vol. XXIX., 1879. Ueber Reizung contractilen protoplasmas durch plötzliche Beleuchtung und Engelmann. Ueber Licht und Farbenperception niederster organismen. Pfluger's Arch. Vol. XXIX.

light is directed, the alga is seen to lean itself upon the bottom of the receptacle by one of its extremities, and then place itself in such a position that its axis coincides with the direction of the incident light.

If the incidence of the rays of light be suddenly varied the alga pivots itself anew upon its extremity, which sustains it and goes again to place itself in the axis of the luminous ray.

At the end of a certain lapse of time, from 6 to 8 minutes, the alga executes a veritable *"pirouette,"* and the extremity which served as the *point d'appui* becomes free and directs itself toward the source of light. This shows that there is then a true phenomenon of polarity and of alternate polarity. Pleurotenium and the Micraserias Rota also exhibit the phenomenon of constant or alternating polarity.

The zoösphores of the algæ are equally phototaxic. They are drawn toward the luminous source by placing themselves in the direction of the incident ray, but turning always toward the latter, their non-ciliated extremity.[1]

With pluricellular algæ, the protoplasm in the interior of the cells exhibits a true phototaxy, as in the case of the vaucheria, where the grains of protoplasm charged with chlorophyll dispose themselves in two bands perpendicularly to the direction of the incident ray, or in the case of the mesocarpus in which each cell is terraced following its axis by a protoplasmic plate charged with chlorophyll which, under the influence of the light energy, turns itself so as to be perpendicular to the radiation.[2]

Myxomycetes, referred to under the action of light upon vegetable organisms, are either positively or negatively phototaxic according to the degree of light energy. A light of feeble energy excites the stretching of their protoplasm

[1]Strasburger: Wirkung des Lichtes und der Wärme auf Schwärmsporen. Jena, 1878. Also, Stahl: Ueber den Einfluss des Lichtes auf die Bewegungs erscheinungen der Schwärmsporen. Verhand. der physic. medic. Gesellschaft, in Würzburg, t. XI, 1878.

[2]Stahl: Botanische Zeitung, p. 297, 1880, quoted by Leredde and Pautrier.

and extends them; one of medium energy leaves them indifferent; but a light of intense energy causes them to run or to retract sharply with formation of granules in their interior.

The Pelomyxa palustris is an example of negative phototaxy. This curious observation was made by Engelmann.[1] The pelomyxa is a rhizopod and is analogous to the amœba which is found in the shade at the bottom of ponds concealed in the slime. Its protoplasmic body is rough, heavy and bare. It advances by putting forth flat pseudopods. Abandoned to itself, it progresses by movements of repetition, taking an elongated form and following a certain direction, but always the same. Upon exposure to light it contracts in a few seconds after the granule streaming has ceased and takes the form of a ball. If a weak light is maintained slow movements are again to be seen. When the darkness is dissipated by the gradual coming on of daylight there is no irritant action. Many myxomycetes comport themselves in an analogous fashion.

Flowers of tan flee from a bright light, which causes them to retract. Strasburger[2] picturesquely demonstrated the action of light on the plasmodia of œthalium; under the influence of a feeble light, he was able to call it to the surface of a tan ditch, and upon suddenly increasing the brilliancy of the light it was made to rebury itself in the ditch. In the light they develop short, compressed projections, with dark, long, thin, narrow processes.

Hofmeister,[3] in his studies upon the rôle of light in the relation to myxomycetes, observed that the Œthalium septicum fled from the light, and always in the direction of the light rays. This is illustrative of the negative heliotropism of these bodies.

The Pholada dactyle, a marine mollusk observed by

[1]Engelmann: Ueber Reizung Contractilen Protoplasmas durch plötzliche Beleuchtung Pflüger's Arch. Vol XIX.

[2]Quoted by Leredde and Pautrier.

[3]Hofmeister: Die Lehre von der Pflanzenzelle.

Raphael Dubois, has been found to give evidences of phototactism in that part of the animal's body which is the seat of the dermatoptique vision. These phenomena seem to indicate that light in these instances acts in the same way as do artificial irritants.

Transformation of Form under the Influence of Light Energy.—The action of light energy upon these elementary forms of life is not confined, however, to excito-motor phenomena, abundant as these are, as is evidenced by the contraction and extensions of protoplasm. The arrangement of the protoplasm of amœboid cells, amœbæ, rhizopods, infusoria is markedly changed by exposure for any length of time to light or darkness as well. The action is then upon the form, producing modifications which are alike durable and definite. By its action the properties of protoplasm also may be completely modified and caused to assume new forms. These phenomena have been fully investigated by Brefeld[1] upon the Mucedines, also by Elving[2] and Laurent.[3]

Brefeld's work was carried out upon the Coprines, and he concluded that for the Basideo-Mycetes the development in light and darkness is very different. In darkness the development is bad, the head shortens, the foot is enormously elongated also.

The organs of fructification appear only in the light, in the darkness the mycelia are sterile.

Laurent's studies were upon two of the Hyphomycetes, the Dematium pullulans and the Cladosporium herbarum. He was able to derive the first from the second by sowing some spores of Cladosporium into must (moût) of beer and exposing them to the action of solar light energy. After some days of insulation these spores, transported into a new must of beer, developed growing forms of Dematium. They not only changed form but properties as well: the Clado-

[1]Brefeld: Botanische Untersuchungen über Schimmelpilze.

[2]Elving: Studien über den Einwirkung des Lichtes auf die Pilse. Helsingfors, 1890.

[3]Laurent: Annales de l'Institut Pasteur, 1888.

sporium being exceedingly aërobic, while the Dematium can live in anaërobia.

By the sowing of some spores of Aspergillus glaucus in must of beer exposed to the action of solar energy, Elving obtained three kinds of yeast forms. These returned to darkness gave in their turn some new yeast forms, which were not developed after the type of Aspergillus, but after the type of Penicillium. This latter type was definitely fixed and was uniformly produced in subsequent generations.

Passage of Aërobic Life to Anaërobic Life under the Influence of Light Energy.—This phenomenon is observed in the purple bacteria as well as the motor phenomena described under the action of light. It will be recalled, movements are established upon their passage from darkness to light and upon their return to darkness, complete immobility. There is also a true modification of vital conditions, i.e., a passing alternately from the anaërobic state to the aërobic state and inversely.[1]

The Bacterium-Photo-metricum, studied by Engelmann[2] is the type of the best known of the purple bacteria. This micro-organism is exceedingly sensitive to the stimulus of light energy. So long as it is exposed to the light it propels itself swiftly about in the drop of water by the aid of the scourge-like thread which is found at the end of the bacterial body. Upon its return to darkness the movement of the thread gradually ceases and the bacterium remains motionless, to be stimulated again, however, to fresh movement under a renewal of the light energy.

It was observed upon examination in the drop, covered with a cover glass under the influence of a very feeble light, to approach the borders of the plate; while in a stronger light it remains collected in the centre of the preparation. In this latter instance it is very far from the oxygen. In the first instance the condition is the same in the diffuse

[1]Leredde and Pautrier.

[2]Archiv. f. d. ges. Physiologie, XIX., p. 1. and Handbuch der Physiologie, Vol. I., p. 370.

light as in the dark and there is need of a source of oxygen in order that it may live, hence it seeks the edge of the plate; in the second on the other hand, when exposed to the bright light, by means of its coloring matter, which is supposedly similar to chlorophyll, it is enabled to find the necessary oxygen in the decomposition of the ambient carbonic anhydride.

Action of the Different Frequencies of Light Energy Upon Elementary Life.—Thus far the action of the total light energy has been studied but certain investigations have been made, showing that there is a difference in effect from the different frequencies of the spectrum. This is illustrated by the following interesting experiments of Verworn.[1]

Verworn examined with a microscope a ciliated infusorium, the Pleuronema chrysalis, which ordinarily is in a state of repose, that is immobile in water without ciliary movement. When under examination, if the diaphragm of the microscope be raised, the infusorium exposed to the action of light appears to leap impetuously, after a period of one to two seconds or latent period of excitation.

Verworn analyzed the influence of the different frequencies by interposing between the source of light and the plate of the microscope colored liquids, the transparency of which to the various frequencies had been determined by spectrum analysis.

He found that the maximum effect upon the leaping movements was obtained by the action of the blue and violet frequencies. To obtain the same effect where the thermal energy was utilized, it was necessary to have recourse to intense solar light, concentrating the energy by means of a concave mirror. Freund states that the same effect can be produced with intense heat rays.

The Action of Light upon the Ciliated Corpuscle.—Bergel has carefully studied the effects of light and darkness upon the movement of the ciliated corpuscle in the fol-

[1]Allgemeine Physiologie, Jena, 1895.

lowing manner: The microscope was placed upon an observation table within a dark cabinet. This cabinet was perfectly closed save for two openings. The one when illuminated was for the observer but when it was desired to shut off the light it was carefully darkened by curtains. Opposite the microscope was another opening which could at will either be closed or exposed to direct sunlight. Then by placing a ciliated corpuscle in motion under the microscope and darkening the window permitting the light to fall upon it, the motion of the corpuscle could be seen on inspection to grow slower and slower until it finally ceased. The more rapid and energetic the vibrational activity of the corpuscle before the window was darkened, the longer the period of activity of the corpuscle in the darkness, until it finally became motionless and *vice versa;* the slower and weaker the vibration of the cilia the shorter the time up to the cessation of all motion. But on the contrary, when a corpuscle which had kept in the dark and showed no motion whatever, was exposed to the bright daylight again the oscillation recommenced after a latent period, depending upon the duration of the exposure to darkness. The longer the corpuscle remained in the dark after it had become motionless the longer it continued in a quiescent state before resuming its oscillations. When the corpuscle was kept too long in the dark it showed every evidence of fatigue. This fatigue was also noticed when the experiment was repeated several times.

These experiments indicate not only a direct action on the ciliated epithelium of the respiratory tract and the necessity for light energy in respiratory pathologies, but illustrate as well the physical effect of the oscillating swing of light vibrations on atomic motion. At least this is the writer's interpretation of these very interesting experiments, nor do the phenomena produced admit of any other in the light of physical laws.

It is stated by Freund that, according to Uskoff, the ciliary movement of the epithelium of the œsophagus is equally swift in red and in violet light, but that it is sus-

pended if red light is substituted for previously acting violet light. Even among the ciliary infusoria, isolated specimens are found whose movements are stimulated by light.

Strassburger and Miguel have demonstrated that the phototaxic sensibility of the algæ, of their zoöspores, of the protoplasm of the Vaucheria or of the Mesocarpus is not brought into action by all the frequencies of the spectrum. The active frequencies are the blue, indigo and violet. The red and infra-red have absolutely no action.

The phototactic movements of the plasmodia of Myxomycetes are also under the influence of the most refrangible frequencies and are unaffected by the other frequencies of the spectrum. The bacterium Photo-metricum of the purple bacteria group is an exception. Engelmann[1] found upon examination of a drop of liquid containing a great quantity of these bacteria upon which a solar spectrum was projected that they accumulated with a particular predilection at certain points corresponding precisely with the absorption bands of the bacterio-purpurine, that is in the infra-red and in the orange and yellow. These therefore were the frequencies necessary to excite movement in the bacillus photometricum.

Thus far it has been shown that the movements of these bacteria are possible only if the oxygen necessary to them is furnished by the decomposition of the ambient CO_2 through the intermediary of the coloring matter which impregnates them.

It will be seen as with plants that the frequencies most useful to them are those which correspond to the absorption bands of chlorophyll. The conclusion is therefore permitted that the bacterio-purpurpine plays for the purple bacteria a rôle analogous to that played by chlorophyll for plants and the predilection of these bacteria for the red frequencies are explained by a functional adaptation.

[1]Bacterium Photometricum. Ein Beitrag zur vergleichenden. Physiologie des Licht und Farbensinns, Pflüger's Archiv., Vol. XXX.

Leredde and Pautrier in reaching this conclusion, regret that the studies and experiments of Laurent and Elving upon the change of form and of function under the influence of light were made only under the influence of the total light energy and that they did not see fit to analyze the action under the influence of the different frequencies.

Summary.—From a careful review of these very interesting observations of Engelmann, Laurent, Strasburger, Uskoff, Brefeld, etc., it is clearly evidenced that it is the blue, indigo and violet frequencies which are the effective ones.

By the action of light, and especially of the more refrangible frequencies, a series of phenomena are produced at the level of the protoplasms:

(1) An excito-motor action, i.e., the extension of the various movements of protoplasm.

(2) An influence on the growth and reproduction of the mycelium of the algæ.

(3) An extension of forms in one species lasting modifications faithfully reproduced by successive generations.

(4) The concurrent establishment of a complete overturning of the conditions of existence to the point of permitting an exclusively aërobic organism to become anaërobic.

In a study of the general physiology of the elementary forms of life, concludes Leredde and Pautrier,[1] the influence of light assumes an important place. The excito motor phenomena are the best known and studied. To produce them the action of the indigo, violet and ultra-violet frequencies are required.

[1]Photobiologie and Photothérapy, Leredde and Pautrier.

CHAPTER IV.

The Action of Light Energy upon Vegetable Organisms.

The necessity of plant life for light is greater than that of any other living organism. This is axiomatic. Without light energy plants become colorless, of imperfect structure and growth. In the absence of light it is impossible for them to take from the air the carbonic acid, absolutely indispensable to their existence. Nor can they by means of the chlorophyll assimilate it to their needs, setting free oxygen in the process, and retaining the carbon in new combinations, such as sugar, gum, starch, cellulose and albumen.

A study of the action of light upon vegetable organisms is much less complicated than that upon animal organisms, by reason of the absence of the nervous system in the former.

It is assumed by most physiologists that there is a direct chemical effect from light energy on the chlorophyll. This effect is dependent not only upon the intensity but upon the quality of light. All the frequencies of the spectrum have been shown to possess the property of producing chemical effects, although it is the higher and more refrangible rays as indigo, violet and ultra-violet which are regarded as especially active. The chlorophyll function, that is the decomposition of carbonic acid, however, depends upon the longer and less refrangible frequencies of the spectrum, the red and yellow.

It is clearly established by the experiments of Siemens, Dehérain and Bailey that the intense chemical energy of the ultra-violet frequencies is badly borne by plant life. For each class of plants a certain intensity of light energy is necessary for the most perfect performance of its assimilative processes; others again require but little light energy. The latter are those plants which are found in shady nooks, water courses, in dim forest aisles and in the depths of the ocean, ferns, mosses and marine algæ, for example. Of the sun-loving plants, the sunflower is a notable example, turning his face always sunward.

Life of Plants in the Dark.—It has been proven by the experiments of Boussingault[1] that a plant destined to be green when kept in the dark consumes its reserves and loses weight; the life of a plant, coming out of the sea and kept in the dark, depends upon the amount, i.e., weight of nutritive matter contained in the sea.

Necessity of Light for the Development of Chlorophyll.—It has been established by Timiriazeff[2] that the characteristic pallor of plants kept in obscurity is due to the presence of protophylline or reduced chlorophyll. When they are transported to the light, they become green through the absorption of the light energy by the protophylline.

There is another pigment existing in leaves, alongside of the chlorophyll, red in color, the erytrophyll of Bourgarel or carotine of Arnaud,[3] whose rôle is very little known. The most vigorous leaves, which means those of the deepest green, furnish the largest proportion of carotine; it is observed that it tends to disappear as does the chlorophyll when kept in darkness.

Exceptions to the Necessity for Light in the Development of Chlorophyll.—Chlorophyll appears in some plants budding in obscurity contrary to the general law.

[1]Agronomie, V. 246.

[2]Comptes Rendus, Acad. des. Sc. t. CII., p. 686, 1886.

[3]Comptes Rendus, Acad. des Sc. C. 751, 1885; CII. 119, 1886; CIV. 1295, 1887; CIX. 991, 1889.

Flahault[1] has shown that the bulbs of crocus vernus planted in the dark gives sprouts whose extremities are green.

It has also been proved by Bouilhac[2] that the Nostoc punctiforme, develops a pale green tint in total darkness, if it finds at its disposition a hydrate of carbon, such as glucose.

Grass when turned down continues to grow in the soil and presents a feeble green tint. This was noted by Kraus, but is a matter of common observation.

A green alga has been found by a polar expedition at a depth of 2,000 metres in the Atlantic. Light penetrates into water but 200 metres, so that here is an organism taking on its green coloring.[3]

Flahault and Griffon[4] have by their experiments proved that the substance in the plants grown in darkness is really chlorophyll. Flahault examined an alcoholic solution spectroscopically while Griffon caused some cotyledons of Pinpignon to assimilate which had developed in darkness. Exceptionally then it is seen that chlorophyll forms in the absence of light a phenomenon at this time unexplainable.

Chlorophyll Assimilation; the Rôle of Light Energy in this Function.—The action of light in relation to chlorophyll assimilation has been thoroughly investigated independently of the respiration of plants. Among the modern botanists whom have studied the subject especially are Bonnier and Mangin.[5] They have shown that the two phenomena, i.e., respiration and chlorophyll function are distinct in their mode of action. Respiration, that is the absorption of oxygen and the exhalation of carbonic dioxide, goes on equally in light and darkness. By anæsthetizing the plants under ob-

[1]Ann. Soc. Nat. Botan. 6th Séries t. IX. p. 169.

[2]Comptes Rendus, Acad. d. Sc. May 3, 1898.

[3]Leredde and Pautrier.

[4]L'Assimilation Chlorophyllienne, Paris, Naud, 1901.

[5]Bonnier and Mangin, L'Action Chlorophyllienne Séparée de la Respiration. Compt. Rend. Acad. d. Sc., t. C., p. 1303, 1885 et Ann. Sc. Natur. 7th Série t. III., p. 5, 1886.

servation they have proved the independence of the two functions, and found that darkness does not influence respiration, but that absence of light suppresses the chlorophyll function.

Chlorophyll production and function are dependent upon the presence of light. But chlorophyll is not the only substance capable of fixing carbon under the influence of light. De Candolle[1] has showed that the red algæ can disengage oxygen in the light; while Engelmann[2] thinks that the different coloring matters of the algæ, phycocyanine, phycoerythrine, and bacterio-purpurine of certain algæ of the category of the *bactériacées,* are also instances of assimilation carried on and dependent upon the influence of light energy.

At the base of all plant physiology is then this essential primordial phenomenon, or the assimilative phenomenon *par excellence* of the plant, which consists of the decomposition of CO_2 of the ambient medium and assimilation of carbon.

This phenomenon is produced by the intermediary of a series of colored substances or chromophylls, of which chlorophyll is the most diffused.

This assimilation of carbon is an essential exothermic reaction; for its production, it is necessary that an external energy should be operative, and this energy is furnished in light. It is the absorption of light by the chloroleucites, or by the other colored substances analogous to chlorophyll, upon which the chlorophyll function depends.

Nature of Chlorophyll Assimilation.—It is an established fact that under the influence of light energy a plant provided only with water increases its weight of dry matter; it fixes, in other words, its assimilative carbon.

The author finds in this a counterpart of the action of light upon the blood. In the latter instance it is a fixation or storing of oxygen, so necessary to animal life.

This exothermic reaction of chlorophyll assimilation produced by light is believed[3] to be produced in the plant or-

[1]Physiologie Vegétale, t. I., p. 119.

[2]Botanische Zeitung, 1883

[3]Berthelot.

ganism simultaneously with the decomposition of CO_2, from the compensatory reactions which furnish the necessary energy.

The Effective Frequencies of Light Energy in Chlorophyll Assimilation.—The decomposition of carbonic acid by chlorophyll is dependent upon the less refrangible rays, red and yellow. Plants and parts of plants grown in the dark have no chlorophyll; the chlorophyll pigment being found in the light. From absence of light they become pale yellow in color, a condition known as etiolation.

The experiments of Siemens, Bailey and Dehérain, to be referred to later on, showed that the electric arc gave a light needed for chlorophyll; but for that matter all artificial sources of light may take the place of sunlight so far as chlorophyll is concerned, for they all give out the yellow frequencies. It has been proven that sprouting plants will grow dark green in a light barely sufficient for the reading of large print. This shows that the quantity of light need not be large.

By the utilization of various colored solutions, as filters, the different frequencies were cut off at will in the experiments made to determine the part of the spectrum necessary to the production of chlorophyll. For this purpose Pélétier's bell jars were used.

The chemical theory of the action of light energy on chlorophyll is the most widely accepted one. To it is opposed that of Pringsheim.[1] The latter holds that the chlorophyll pigment by the absorption of blue, violet and ultra-violet frequencies, without being decomposed itself, acts as a kind of light screen, lessening the degree of respiration, that is, the oxidation connected with the elimination of CO_2, and increasing thereby proportionally the assimilative processes, especially as they pertain to the collection of carbon and the giving off of oxygen, within the plasma of the chlorophyll body.

[1]Jahrb., XII., 1879-1881, p. 288, Quoted by Goodale, Physiological Botany, Gray's Botanical Text-book. Vol. II.

The subject of the frequencies of light energy most favorable to chlorophyll development has been extensively investigated by Gardner, Draper, Daubeny and Guillemin. Guillemin used successively a spectrum obtained by 3 different prisms, (1) an ordinary prism, (2) a quartz prism, and (3) a rock-salt prism. In the first instance, all of the energy save the ultra-violet was allowed to pass, in the second the ultra-violet, while in the third the infra-red were permitted to pass.

Later experiments by Timiriazeff places the maximum energy in the red region between the lines B and C. In other words in that part of the spectrum absorbed by chlorophyll. Always wherever in nature it occurs, there is a constant proportion between the energy absorbed and the work done.

Theory of Complementary Colors.—Engelmann has advanced the theory that it is always the frequencies complementary to the color of the plant whose action is the most pronounced. This is not confirmed by other physicists, and is especially denied by Pringsheim.

The Action of Chemical Frequencies.—For the chlorophyll function the energy of the chemical part of the spectrum is necessary. Bonnier and Mangin have found that this assimilation also takes place in the presence of ultra-violet energy. The amount of this assimilative energy has been measured by the CO_2 decomposed.

Experiments made upon the leaves of Arachidium and of maize give the following results:

LIGHT ENERGY.

	Blue.	Red.	Green.
	cc	cc	cc
Arachidium	0.054	0.041	0.027
Maize	2.440	1.602	0.823

There is then a correspondence between the amount of energy and the intensity of the green coloration; conditions which are realized to the greatest extent from the effect of the blue frequencies.

Just here the reader must be impressed with the similarity of effect upon the human organism. It is the blue frequencies of light energy even into the ultra-violet, which are absorbed by the blood, and there exists in the human being a distinct relation between the energy which he is capable of exerting and the intensity of the color of the red media.

Influence of Light Energy upon the Growth of Plants—Actinauxism.—Dufour[1] from his experiments found that other conditions being equal, the plant growing in the light is more voluminous and more robust than that which has lived in semi-obscurity. Its leaves are more rich in stomata, its cells better walled, its grains of chlorophyll a great deal larger and more abundant and its assimilative energy much greater. This retardative action of light known as actinauxism is profoundly beneficent to the plant. It is a matter of common observation that in the dark the stems of a plant elongate more than in the light. This increase in length is not due to the production of new cells but to an exaggerated increase of cells already formed. It is not a phenomenon of over activity but rather one of degeneration. In the presence of light energy the growth is retarded, which is to the benefit of the plant, for there is thus secured the solidity, the equal partition of the *chloroleucites,* which are absolutely essential to its life. Plants grown in darkness are so slender, so lacking in fiber, that they are unequal to the support of their branches.

Plants grown in the dark have very long internodes and leaf-stems but practically no leaf surface. Through the effect of light in the assimilation of carbonic acid the growth of green leaf surfaces is accentuated.

The Transformation of Light Energy into Electro-Motive Energy.—Light energy is transformed in the plant by the changes of matter, and Waller[2] proved that light de-

[1]Influence de la Lumière sur la Forme et la Structure des Feuilles. Ann. Sc. Nat. bot. 7th Série, t. V. p. 311, 1887.

[2]Compt. rend. de la Soc. de biolog. 1900, LII., p. 1903.

velops an electro-motive energy in the assimilating leaf more by the bright red frequencies, especially those absorbed by the chlorophyll, than by the heat rays.

Biedermann's[1] researches show that certain plants, among them iris, nicotine, begonia and nasturtium, are more favorable than others to demonstrate the existence of electric currents. If one of them be placed in connection with a galvanometer by means of electrodes attached to leaves on different sides, and one side of the plant be exposed to sunlight while the other side is kept shaded, then within from 3 to 10 seconds after exposure to sunlight there will be a flow of electricity from the lighted to the shaded parts amounting to .005 to .02 volt. This continues for about 5 minutes, when the magnet begins to swing back and shows an opposite current of considerable magnitude. The manifestations are similar to those of tetanized nerves. The electric current of green leaves is least in diffused daylight, greater in refracted light and most in direct sunlight. It is still further affected by the temperature, 20°C. being the optimum for iris. The electric activity is destroyed by cooking the leaves nor are the electric manifestations found in plants that do not have green leaves. Biedermann concludes that this is proof that the generation of electro-motor force accompanies the decomposition of carbon dioxide of the air, the exhalation of oxygen, and the fixation of the carbon of the air.

Influence of Light Energy upon the Movements of Plants.—In the transformation of energy which takes place in plants there may be distinguished two great groups of movements, viz., the movement of growth and the movement of irritation.

Growth Movement.—Under the stimulus of light energy, plants present definite growth movements, which may be regarded as irritation phenomena. When certain parts of a growing plant with a definite periodicity move automati-

[1]Dr. W. Biedermann, Ergebnisse der Physiologie.

cally one or more times, the phenomenon is known as nutation. Of those periodic nutation movements made by the green leaves is that known as nyctitropic nutation. By this is understood the closing and the folding of leaves either upwards or downwards against the common stem, according to the kind. It is the movement characteristic of sleep or rest. In the daytime the leaves are spread open that the light may fall upon them vertically. The sleep movement prevents the plant from too great radiation at night. These movements are due to the blue and violet frequencies. Red has the same action as the absence of light.

The growth movement is not dependent upon light under all circumstances. It is not required for the process of germination, nor for the growth of the roots and many blossoms. It is necessary for the growth of many living parasites, both the endophytic, or those living in the body of plants, and endozooic, those living in the body of animals.

In general light retards the growth under the conditions enumerated and this is also true of organisms above ground. By reason of this fact, the varying rate of growth at different times of day is explained. This rate is not for a time influenced by artificial exclusion of light. It is in the morning that stems and leaves grow most actively and least in the evening.

The growth of plants is lessened by all the frequencies of the spectrum except the red and infra-red, as will be seen from the effects of the electric arc in the experiments to be detailed under that head. The most refrangible frequencies are the most injuriously active not only lessening the growth but destroying the organism in part.

Influence of Light Energy upon the Structure of Plants—Heliotropism.—By heliotropism is understood an unequal development of the two sides of a plant, according to its relation to the source of light energy.

It is a matter of common observation that certain plants when left in a room lighted from one side only, incline toward the source of light. It was demonstrated by von

Sachs[1] that in plants lighted from one side only radial structures, stems and roots, bend until their long axes are parallel to the rays of light, and that dorsiventral structures, leaves, for example, assume a position in which their surfaces are perpendicular to the light rays. To those plants or organs which turn toward the light von Sachs applied the term positively heliotropic, while those which turn from the light were termed negatively heliotropic. He formulated the three following laws, viz.: (1) The orientation of a plant toward or from the source of light is determined by the direction of the rays. (2) Orientation of plants is affected only by the more refrangible rays, blue and violet. (3) Light of constant intensity acts continuously as a source of stimulation.

Stems and leaf stalks are as a rule positively heliotropic, while roots and rhizomes are almost all negatively heliotropic. In the former instance they grow toward the light source in the direction of the light rays, but in the latter they turn away from the light source.

To the entire phenomena, however, the term heliotropism is applied. A still further modification of this heliotropic faculty is observed in the case of green leaves; they turn themselves at right angles to the direction of light and are said to show a transverse or dia-heliotropism. If plants be moved from their normal position, their heliotropic movements take on curved movements, according to their relation to the source of light. Heliotropism is governed by the degree of brightness of light. When the light is very bright, organs which are usually positively heliotropic may become negatively heliotropic. This is an instinctive effort at self-preservation, for too much light is inimical to the normal development of the plant as well as too little. The direction of the incident light governs the heliotropic curvature.

This phenomenon has been extensively studied by Wiesner,[1] Guillemin[2] and von Sachs.[3] They have found that the action begins with the frequencies of the green region and goes on up even into the ultra-violet, extending even beyond some radiations which impress salts of silver. The yellow frequencies are neutral, but on the other side the action is the same, rising on the side of the red but very feebly.

[1]Vorlesungen über Pflanzen, Physiologie, Leipzig, 1887.

Microscopically this heliotropism shows itself by intracellular displacements, by protoplasmic currents, by a true phototaxy of the grains of chlorophyll themselves which come and distribute themselves upon the irradiated surface.

This heliotropic action was very prettily shown in 1890 by George Romanes[4] in his demonstrations before the British Physiological Society of experiments which he had made with fresh tender mustard plants.

He sowed the seed in suitable small receptacles, and when it began to sprout placed them in a dark chamber. In this chamber electric sparks were produced by an induction coil at varying rates. Invariably the plants turned their tops in the direction of the sparks, even when these were produced so slowly as once a minute. It would seem as though every tiny plant were looking toward the source of light. The experiment is an interesting one. Whether the phenomenon produced was due to the presence of ultra-violet frequencies only, is conjectural. There is the electric action to be reckoned with and the ionization of the air produced by spark discharge.

The Helianthus is a very striking example of this heliotropic faculty. On a sunny day it orients its stem toward the east after the rising of the sun follows the sun even to the middle of the day, remains there immobile, until toward the end of the day it leans toward the west, resuming the vertical position during the night.

[1]Die heliotropischen Erscheinungen in Pflanzenreiche. Denkschriften der k. Akad. der Wissenschaft. zu Wien. t. XLIII. 1880.
[2]Ann. des Sc. Natur., 4th Série, t. VII. p. 161, 1857.
[3]Botanische Zeitung, 1865.
[4]Roswell Park. A Report upon the Physics and Therapeutic Value of Cathode and Ultra-violet Rays. The Medical News, May 30, 1903.

Locomotor Movements.—A study of plant life shows that many unprotected plasmic bodies, such as the swarm spore of many algæ, present the phenomena of independent movement by means of their waving cilia. This movement is governed in part by temperature, and in part by the action of the incident light. These locomotor movements may be regarded as one of the irritation phenomena produced in plants by the stimulus of light energy. Microscopic inhabitants of the ocean, ponds, and lakes, just as larger animals change their position by reason of the influence of light. Sunlight attracts them, and they often rise to the surface from the depth of the waters in which they live. The water changes in appearance, loses its transparency and takes on different colorings, dull green, bluish brown, or red when they are present in great numbers. Prominent among the algæ, which will actually move themselves upon exposure to light, is a whole series of the Desmidia, particularly the Closterium moniliferum.

Water plants, however, appear at the surface of the water, by reason of their production of oxygen, which lessens their specific gravity. Reproductive cells of the algæ, swarm spores, zoöspores, which are capable of independent movement, as are the infusoria, move as far as possible in a straight line toward the source of light. This is a heliotropic movement, but some such cells are repelled rather than attracted by light, and are, therefore, regarded as negatively heliotropic. Whether they turn on the longitudinal axis of their body or not, that is to right or left, again depends upon the light ray.

Heliotropism is dependent, as are so many of the phenomena of plant and animal life, upon the short and high frequencies of the blue region of the spectrum; while the frequencies of the red region, like darkness, do not affect their action at all. The creeping or amæboid movements exhibited by the plasmodia of myxomycetes, as of "flowers of tan," are dependent upon the stimulus of light energy. These bodies move away from the bright spots into the

shade, working themselves slowly along on their base. They are, therefore, negatively heliotropic. The movements of chlorophyll bodies are possibly dependent on this plasma movement, and seems to bear a relation to the greater or lesser intensity of light.

Every lover of nature is familiar with the intense deep green of the leaves of phanerogams, mosses and the prothallia of ferns. This is due to the slow changes in the position of the chlorophyll corpuscles in the protoplasm. Under the influence of the stimulus of light energy, especially the shorter and higher frequencies, these chlorophyll corpuscles collect mainly in the cell surfaces turned toward the leaf. While in the dark they collect mainly along the side walls of the cell, at right angles to the cell surface. Whether this is a direct influence of light upon the protoplasm, or an indirect unfluence induced possibly by primary change in the chlorophyll corpuscles, is not certainly known. The position of the chlorophyll corpuscle varies during night and day. According to Stahl the position for the most part of flat chlorophyll corpuscles with regard to the incidence of light is divided into the "surface position" and the "profile position." The position of the chlorophyll corpuscle in all cases is governed by the following general rule: (1) When the stimulus of light energy is at a medium of brightness, the chlorophyll corpuscles turn so as to present the broadest surface possible. (2) When there is a maximum of light energy, i.e., direct sunlight, they turn their narrow edge to the light. (3) When there is a minimum of light energy, or darkness, the narrow edges are turned, as when the sun's direct rays fall upon them.

In the second instance they present the edge of the leaf that the light energy may not be absorbed and act destructively; while in the absence of light energy the change of position is that of rest or sleep. This movement is the property of the chlorophyll corpuscles or bodies in all assimilating tissues.

They also change in form according to the degree of

brightness. When the stimulus of the light energy is most favorable to their needs they assume the flattest position, that is, a position horizontal to the superficies of the leaf. In common with the pigment cells of animal organisms chlorophyll corpuscles are capable of contraction. This again is dependent upon the energy of the light stimulus. The green of a plant may take on a lighter or darker shade according to the degree of light energy. This characteristic of the chlorophyll corpuscles of plants finds its counterpart in the pigment cells of the chameleon. The protoplasmic current in plant cells, which frequently is only recognized under the microscope after mechanical stimulation, seems ordinarily to be independent of light, although it is proved to be governed by temperature and the presence of oxygen or contained water. The exclusion of light does not affect the protoplasmic current. It goes on just the same as far as is now known. External conditions, however, may be so changed that the protoplasmic current may after all be radically influenced by light. Experiments were made by E. Josing as follows:[1] (1) objects with freely flowing protoplasm were subjected to the effect of weak solutions of ether or chloroform, and (2) the constituent of the air necessary to their life, carbonic acid, was withdrawn by means of a suitable agent from the air. Under these conditions the protoplasmic current ceased to flow when the light was excluded, but resumed its course upon its readmission.

The injurious effects of electric arc light, which is, after all, but a miniature sun, were first noticed by Siemens in 1880, as is shown in subsequent pages.

Data as to the injurious effects of light on plants was first furnished by Pringsheim. There are no changes especially characteristic of these injurious effects. The following conditions have, however, been noted: rigidity, formation of nodes, concretions of plasma, granulations, especially in the cell nucleus, but without any especial characteristic. There is no such intense nor disruptive effect produced by light energy, when acting injuriously, as by heat. A sudden change of temperature intensifies corporeal movements. On the other hand, a maximum light intensity tends directly toward precipitation in the plasma and toward its rigidity. Contraction occurs only upon death supervening, but vacuolization does not take place.

[1]Jahrb. d. Wissensch. Botanik, 1901, Vol. XXVI.

Influence of Light Energy upon the Blossom.—The color of flowers is influenced by the different frequencies. By using various colored lights, various shades of the lilac, for example, may be obtained. The influence upon the aroma under the red frequencies is very great. Strawberries thus grown have a very delicious aroma and crassula flowers, which are nearly scentless in ordinary sunlight, give out a delicate banana-like fragrance.

The absence of light retards the development of flowers, and their color is less intense in darkness than in sunlight. This diminution of intensity of coloring varies with the species, with some there is little change, but with others a complete loss of coloring. As a rule, flowers thus developed are smaller, but on the other hand the peduncles are sometimes more fully developed. They also are less in size and weight, including the supporting pedicles, save in those instances where the increase in the size of the peduncles counterbalances the diminution of the rest of the plant.

Plant life in common with animal organisms is subjected not only to the chemical effect of light, but the thermal or heat effect as well.

Following the introduction of electric light, the influence of the latter in relation to plant life was studied. The first experiments were made by Hervé Mangon in 1861.[1] By this experiment he showed that the electric light can cause the production of chlorophyll and also heliotropism, or the phenomena of bending or turning to the light.

In 1869 Prilieux[2] showed that the electric light, in com-

[1]Compte Rend. 53, 243.
[2]Compte Rend. 69, 410.

mon with other artificial lights, is capable of promoting assimilation, or the decomposition of carbon dioxide and water. General Pleasanton conceived the idea of growing vegetables and fruits in greenhouses constructed of blue and violet glass, and published his results in 1877. He reported the production of extremely fine fruit, and that the growth of figs was accelerated. These experiments were next followed by those of C. W. Siemens in England and P. P. Dehérain in France.[1] These were still further supplemented by the experiments at the Agricultural Station of Cornell University in 1891 and 1892,[2] the latter comprising the only definite investigation of the subject upon what might be considered a practical or horticultural scale. The English experiments, although eminently practical, were conducted by an electrician, the French were largely confined to physiological problems, while those of Cornell University were approached from the standpoint of the gardener.

In Siemens' experiments, the lamp in the first instance was placed inside the greenhouse and in the second suspended over it. That is, in the first series, all the frequencies of the spectrum of an electric arc from the lowest to the highest were in evidence. In the second series the ultra-violet of less than 30 microcentimetres were cut off. In both cases marked effects upon vegetation in a very short time were observed. His light source measured photometrically produced 1,400 candle-power. When the light was placed inside of the house and no absorbing media for the ultra-violet frequencies intervened plants within 3 or 4 feet of the arc suffered much, the leaves of melons and cucumbers which were directly opposite the light, turned up at their edges and looked as though they had been scorched. In general, however, all plants which were exposed to normal conditions during the day and to 6 hours

[1]Quoted in Bulletin 30, Agricultural Experimental Station. Cornell University, Aug., 1891.
[2]Bulletin 30 and 42.

of electric light at night, "far surpassed the others in darkness of green and vigorous appearance generally."[1]

The electric light fruits had an equally good flavor with the others. Supplementary experiments were made in the following winter 1880-1881, with a lamp of 4,000 candle-power inside a greenhouse of 23,118 cubic feet capacity. The light was in operation all night and at first it was used without a globe. This again meant the exposure of all the plants to the short and high frequencies or ultra-violet rays. "The results were anything but satisfactory." A clear glass globe was then placed upon the lamp, following which most satisfactory results were obtained. Peas, raspberries, strawberries, grapes, melons, and bananas fruited early and abundantly under continuous light; solar light by day and electric light by night. The strawberries are said to have been "of excellent flavor," and the grapes of "stronger flavor than usual." Competent judges pronounced the bananas of "unsurpassed flavor," and the melons "remarkable for size and aromatic flavor." Wheat, barley and oats grew so rapidly that they fell to the ground of their own weight. The effect of interposing a mere sheet of thin glass between the plants and the source of electric light was most marked. On placing such a sheet of clear glass so as to intercept the rays of the electric light from a portion only of a plant—for instance, a tomato plant—the effect was most distinctly shown upon the leaves. The portion of the plant under the direct influence of the naked electric light, though a distance from it of 9 to 10 feet, was shrivelled, whereas, that portion under cover of the clear glass continued to show a healthy appearance, and this line of demarcation was distinctly visible on individual leaves; not only the leaves, but the young stems of the plants soon showed signs of destruction, when exposed to the naked electric light, and these

[1]Proceedings of the Royal Society, XXXI, 210 and 293. Rep. British A. A. S. 1881, 474.
Abstracted in Nature, XXI, 456, March 11, 1880. Editorially treated in the same issue.

destructive influences were perceptible, though in a less marked degree, at a distance of 20 feet from the source of the light.[1] Here the significance of the intense chemical activity of the ultra-violet frequencies cannot fail to be appreciated.

In the other series of experiments Siemens placed an electric lamp of 1,400 candle-power about 7 feet above a sunken melon pit which was covered with glass. The arc was protected by a clear glass globe. In these experiments the light energy was filtered through the media of 2 thicknesses of glass, effectually absorbing all the ultra-violet frequencies. Seeds and plants of mustard, carrots, turnips, beans, cucumbers and melons were placed therein. The arc was in operation 6 hours each night, and the plants had sunlight during the day. In all cases those plants "exposed to both sources of light, showed a decided superiority in vigor over all the others, and the green of the leaf was of a dark rich hue." Heliotropism was observed in the young mustard plants. Electric light appeared to be about half as effective as daylight. The condensed moisture in the roofs of the greenhouses at night obstructed the passage of the light. At one time the light was suspended over two parallel pits nearly 4 feet apart, and the effect was observed upon plants under the glass and in the uncovered space. In all cases the growth of the plants was hastened. Flowering was hastened in melons and other plants under the glass. Strawberries which were just setting fruit were put in one of the pits and part of them were kept dark at night, while the others were exposed to light. The most of the berries had attained to ripeness and presented a rich coloring after 14 days, the light having burned 12 nights, while the fruits on those plants exposed to daylight only had hardly begun to show a sign of redness.

Siemens also noted that the presence of the electric arc light enabled plants in the greenhouses to bear a higher

[1]Siemens' Report.

temperature than they otherwise could. While Siemens' observations and conclusions were applied by him to a practical "electro-horticulture," as he termed it, yet they have a value from the physiological side as well.

The following conclusions were reached by Siemens as a result of his observations:

(1) Electric light is efficacious in producing chlorophyll in the leaves of plants and producing growth.

(2) An electric centre of light equal to 1,400 candle-power, 2 metres from growing plants, appeared to be equal in effect to average daylight in March. More economical effects are to be obtained by more powerful light centres.

(3) That the carbonic acid and nitrogenous compounds generated in diminutive quantities in the electric arc exercise no sensible deleterious effects upon plants enclosed in the same space.

(4) That plants do not appear to require a period of rest in the 24 hours, but make increased and vigorous progress if subjected during the daytime to sunlight and during the night to electric light.

(5) That the radiation of heat from powerful electric arcs can be made available to counteract the effect of night frosts, and is likely to promote the setting and ripening of fruit in the open air.

(6) That while under the influence of electric light, plants can sustain increased stove heat, without collapsing, a circumstance favorable to forcing by electric light.

Dehérain's experiments were conducted at the Exposition d'Electricité in Paris in 1889. A small conservatory standing inside the exposition building was divided into two compartments. One compartment was darkened and the glass painted white upon the inside; this received the electric light and all solar light was excluded. The other compartment was not changed. A lamp of 2,000 candle-power was used. In such an exposition building sufficient sunlight is not received to maintain a healthy growth. The unprotected arc was used first and run continuously. Barley in head and

flax in flower, also chrysanthemums, roses, pelargoniums and a variety of ornamental plants were brought into this compartment. Most of them were seriously injured after seven days of continuous lighting. All the pelargoniums lost their leaves, cannas discolored, four-o'-clocks were tarnished and bamboos were blackened. "But the most curious effect was produced upon the lilacs; all the parts of the leaves that had received the direct rays from the lamp were blackened, while those protected by the upper leaves preserved their beautiful green color, and the impression produced upon the epidermis by the electric rays had the clearness of a photographic plate." Azaleas, deutzias and chrysanthemums were similarly affected. It was found that the discoloration did not extend beyond the first layer of the palisade cells. Those plants subjected to solar light by day and the electric arc by night were injured in the same manner, but not to the same degree. Old leaves suffered most. The pelargoniums sent out mere shoots, and the young leaves resisted the action of the light much longer than the mature ones. The flax continued to grow and the barley ripened. Plants exposed to the electric light alone were able to assimilate, but the action was very slow. One hour of sunlight was equal to several days of electric light in assimilation. In two weeks the condition of the plants was so bad that the arc was thereafter protected by means of a glass globe. The experiments then proceeded in the same manner. Sprouting seeds grew alone in electric light for a time, then drooped and died, not being able to make true leaves. Sprouting maize turned black, but maize in full growth remained in good condition for two months, though not growing any more. While new leaves appeared on roses and other plants, they grew slowly or not at all. In previously formed fruits, seeds did not ripen, nor flowers appear, save in the case of barley, which made good seeds. Many plants remained stationary, and assimilation for all was much more feeble than with the unprotected arc.

Dehérain, in discussing the physiology of the plant under

experiment, came to the following conclusion: (1) The electric light from arc lamps contains rays harmful to vegetation. (2) The greatest part of the injurious rays are modified by glass. (3) The electric arc contains enough rays to maintain full-grown plants two and one-half months. (4) The light is too weak to enable sprouting seeds to prosper or to bring adult plants to maturity.[1]

The experiments at Cornell conducted by Bailey extended over a year, and were made more from the gardener's point of view than those of Siemens and Dehérain. They are of equal interest with those detailed, but as they were made under conditions favorable to the growth and development of vegetation, and for the purpose of showing the value of the energy of the electric arc in forcing establishments, they are not so striking in their injurious effects.

In the experiments of Siemens and Dehérain, the action of the great quantity of the higher and more refrangible frequencies, the blue violet and ultra-violet present, produced in a very marked manner their characteristic effects.

Conclusions from the Cornell University Experiments 1889-1890:

(1) That electric light may be used under such conditions as to make it fairly comparable to sunlight in its power to promote protoplasmic activity.

(2) The electric light acts as a tonic to plants so that they are able to endure adverse conditions which otherwise would cause them to collapse.

(3) That the electric light is a true vital stimulus, since the effect of its use at night upon plants is essentially the same as that of the longer day of the arctics upon plants growing in that region.

Nature[2] in commenting editorially upon Siemens' experiments and the relation of light to vegetation, said: "But the scientific interest of its present application must rest

[1]Am. Agronom. VII. 551 (1881). Quoted by Bailey, Agricultural Bulletin 30, Cornell University, Aug., 1891.

[2]Nature, March 11, 1880.

mainly on the fact that the cycle of the transformation of energy engaged in plant life is now complete, and that, starting from the energy stored up in vegetable fuel, we can run through the changes from heat to electricity, and thence to light, which we now know, we can store up in vegetable fuel again." To-day these experiments as well as those of Dehérain, Bailey and Cornell University serve to still further emphasize the value of light energy from artificial sources for the purpose of treating disease. The author's interest in the subject of light energy was originally greatly stimulated by the result of these experiments.

Conclusion.—From all this mass of experimental data, the paramount importance of light energy upon the vegetable organism is evident. Vegetable life is not possible save in the presence of light. Chlorophyll assimilation, the fundamental phenomenon of plant life, is only possible in the presence of the energy of light. The frequencies of the spectrum influencing this function are the red, orange and the violet. Nor is the rôle of light confined to this phenomenon of vegetable cellular life alone. It plays another most important part in the life of the plant. In connection with geotropism, it rules the direction of the growth of the stem, the leaves, their position, the position of the flowers, in short, it determines some actual movements of the three parts of the plant. In the production of all these phenomena the chemical part of the spectrum is alone active.

CHAPTER V.

The Action of Light Energy upon Bacteria.

Introduction.—In a study of the bactericidal power of light one cannot fail to detect great discrepancies at the hands of different experimenters. These are due to the conditions of experiment. In no instance, at least but seldom, and with solar energy not at all, is the light intensity measured. To be exact, the hour of the day, the nature of the place of experiment, the condition of the sky, clear or obstructed, the light intensity, the temperature and the influence of the culture medium are all factors in the results, and similarity of result will only follow when each and every experimenter takes into consideration all of these factors. For practical work, it is sufficient to speak of the bactericidal power of the light, but not for laboratory experiment.

The influence of these different factors is considered first, with the results obtained by the various experimenters taking them into account. In the subsequent pages the bactericidal power of light is discussed in its more practical relation, rather than in its laboratory relation.

Transformation of Bacterial Species under the Influence of Light Energy.—Aside from the phototactic phenomena presented by bacteria there is also the phenomena of transformation of one species into another under the influence

of light energy, as was described in the case of the Hypomycetes by Elfving[1] and Laurent.[2]

Laurent experimented with the bacillus discovered by Breunig in the waters of the city of Kiel. Light plays a considerable rôle in the development of the coloring matter of chromogenic bacteria, and on the other hand, according to the intensity, acts to suppress the chromogenic function. He found the Kiel bacillus cultivated upon a potato, to show at the end of 24 hours a purple color. From exposing to the light a series of cultures for a varying time, Laurent established that at the end of 3 hours the bacillus was decolorized and modified to the forming of a new race, decolorized and stable. D'Arsonval and Charrin reached analogous conclusions from their experiments with pyocyanic bacilli.

The Influence of Temperature.—It has been observed by Duclaux[3] apropos of the Aspergillus Niger and of the Bacillus Ramosus that in the neighborhood of the critical temperature a difference of a half to a degree between the two cultures can produce profound differences between them.

Influence of the Culture Medium.—This has been carefully considered by Duclaux. The bactericidal action of light is markedly influenced by the nature of the culture medium.

That experiments may have their full value a precise method should be followed: a well-defined microbic species selected, an appropriate culture medium employed, and the time of exposure to the light energy exactly measured.

Duclaux's experiments were made upon the spores of a bacillus of milk, the Tyrothrix Scaber, and upon a coccus found in the boil of Biskra (Biskra-Button—see Chapter XII.), probably identical with the streptococcus pyogenes, and from them he reached the following conclusions:

(1) The degree of resistance to the sun of the spores

[1] Studien über die Einwirkung des Lichtes auf die Pilze. Helsingfors, 1890.
[2] Annales de l'Inst. Pasteur, 1888. C. R. Soc. Royale Bot. de Belgique t. XXVIII, 1889.
[3] Traite de Microbiologie, t. I. Paris, 1898.

of various bacilli is variable with the genus of bacillus, and for the same bacillus, with the nature of the liquid in which it has been cultivated.

(2) It is hardly more than at the end of a month of exposure that these spores, preserved dry in a balloon of glass, begin to become incapable of developing themselves in an appropriate medium.

(3) The cocci, of which the spores are unknown, are more rapidly killed than the spores of the bacilli.

(4) These cocci are less resistant insolated in the dry state than when they are contained in a culture liquid.

(5) The death of all microbes is as much more rapid as the insolation is stronger, and a great deal more prompt even under a feeble sun than in the dark or in diffuse light.

The minimum duration of resistance was in those experiments of 12 hours of insolation in July; the maximum duration of 2 months, for some spores of bacilli insolated dry.

At the same time Arloing[1] made analogous experiments upon a well-defined species, the bacillus anthrax, and made parallel observations upon variations of virulence and variations of vitality produced by light.

By these experiments he proved that gaslight sufficed to retard the evolution of enseminated spores, while sunlight transformed the cultures into a series of "vaccines" gradually attenuated. Arloing found that the spores were killed at the end of 2 hours of exposure in the month of July with a temperature of 35°C.; while it was necessary to have 30 hours of exposure to render sterile the mycelium of the same bacillus in full development. The spores show themselves less resistant to the action of light than the bacilli themselves.

Roux[2] also made a study of the action of light energy upon the anthrax bacillus. He found that the vitality of the spores exposed to sunlight were preserved to the 29th hour at the minimum, while the maximum time was the 54th hour.

[1] C. R., 1885, t. C., p. 378, t. CI., p. 501.
[2] Annales de l'Institut Pasteur, 1887, t. I., p. 445.

After 83 hours of insolation there were some insolated spores, sheltered from the air that gave some beautiful cultures. This is again illustrative of the fact that the microbicidal action of light is dependent upon the presence of oxygen.

As a result of many experiments Roux concluded that, after 3 or 4 hours of exposure, the insolated medium has undergone the chemical changes which renders it unfit for the development of the spores which are not yet killed and will be only by the 30th or 40th hour. The modifications brought about in the medium which are so profound as to prevent the generation of the spores are not, however, sufficient to prevent the evolution of bacilli already formed, which are better able to withstand the light energy. If bouillon which has been insolated and will no longer permit charbon spores to germinate, be sown with bacterium filamentosum, it will multiply there in abundance. Whatever modifications the nutritive medium exposed to the action of light produce, the presence of oxygen is necessary.

Upon exposing charbon spores to the action of the light, Roux found that those contained in open glass tubes with free access to the air became sterile; while those placed in closed tubes would germinate in the same bouillon after insolation, if the containing mass were transferred into an aërated tube.

The Rôle of Accessory Conditions in the Bactericidal Action of Light.—The influences which govern the bactericidal action of light energy are (1) the medium, (2) the atmospheric condition, whether humid or dry, and (3) the influence of the air itself.

A study of the influence of these conditions serves to elucidate the subject still further.

Momont's[1] experiments demonstrated the influence of the medium. He exposed to the sunlight some pieces of blotting paper soaked with charbon blood, and at the same

[1]Annales de l'Institut Pasteur, t. VI., 1892.

time some of the same blood upon sterilized plates. By inoculation he proved that the charbon bacterium was killed on the sterilized plates in 6½ hours of insolation; while the pieces of blotting paper still gave some virulent cultures after 16 hours. In the latter instance, the charbon bacteria were protected by the fibers of the paper.

Momont has also experimented to determine the influence of the atmospheric states of humidity and dryness, but the point is not yet elucidated.

The experiments of Pansini, made at Naples, consisted in exposing tubes containing some sowings made upon gelatin or gelose. These tubes were closed with cotton wool and exposed to the solar energy. A tube was taken each half hour, and placed in the incubator to observe its development.

Pansini concluded that the action of light at first simply retarded the growth, and subsequently proved destructive. The time required for a lethal effect upon the bacterial growths varied with the microbic species.

He has made a very precise series of experiments which show the relation of the bactericidal action of light energy to the time element. Exposure to the sun was made of some pendant drop cultures of anthrax bacillus. The temperature varied between 32° and 40°. He drew from one every 10 minutes to count the germs by the method of plaques.

The second day's examination is as follows:

Plate exposed	10 minutes to sun	360	colonies
" "	20 " " "	130	"
" "	30 " " "	4	"
" "	40 " " "	3	"
" "	50 " " "	4	"
" "	60 " " "	5	"
" "	1 hour 10 minutes	0	
" "	to the same temperature in the dark	2520	"

The spores of the bacteria insolated dry were much more resistant, and gave a table of the following order:

Plate exposed 30 minutes to the light	360	colonies.
" " 1 hour " " "	208	"
" " 2 hours " " "	48	"
" " 3 " " " "	30	"
" " 4 " " " "	34	"
" " 5 " " " "	8	"
" " 6 " " " "	3	"
" " 7 " " " "	3	"
" " 8 hours and more	0	"
Plate exposed in the dark	1015	"

By these tables it will be seen that a much more rapid destruction took place in the first moments of exposure, only, however, to become complete at the end of more than an hour for the bacteria, and of more than 8 hours for the spores.

The Action of Insolated Frequencies of Light Energy upon Bacteria.—D'Arsonval and Charrin,[1] studying the causes of exaltation, or of attenuation of the microbe and the media which they inhabit, analyzed, amongst others, the effects of light upon the bacillus pyocyanicum. Submitting this bacillus to the action of the white light, he found first a diminution of its chromogenic power. He then exposed the "sown" tubes, for a time varying between 3 and 6 hours, one in the chemical part, the others in the calorific part of the spectrum, all the other conditions being equal. Next a drop of each of these cultures was placed upon agar. After 2 days in the incubator at 35 degrees, only the culture submitted to the red light gave pigment, the other remaining colorless. By increasing the time of exposure of the tubes to the light, those that received the violet light remained sterile while the others gave prosperous culture. These authors take care to note the excessive variety of the effects obtained according to the intensity of the luminous sources.

Ledoux-Lebard[2] studied the action of the luminous agent upon the diphtheria bacillus. He proved that the action of diffuse light did not prevent the development of cultures of

[1]Comptes rendus Acad. des Sc., janv., 1894.
[2]Archiv. de Med. Exper. et d'Anat. pathol., 1893.

bacteria, while the solar light sterilized the bouillons of culture in a few days; that diffuse light killed the dry cultures of diphtheria, spread in thin layers, in 24 hours of illumination, and had a bactericidal power for bacilli in dilution in distilled water. He confirmed also the observation that the bacillus of diphtheria, like other microbic species, is killed by the most refrangible rays of the spectrum, the less refrangible rays having no bactericidal action.

The action of both sunlight and that of the electric arc upon the growth, and the life of various kinds of micro-organisms, is then firmly established by extensive and very carefully conducted experiments, and that this action without the living tissue takes place can in no sense be gainsaid. That it takes place in living tissue by the action of the chemical rays which penetrate them, is disproved by the experiments of Bernard and Morgan.

This bactericidal action of light was first pointed out by Downes and Blunt,[1] who in 1877 communicated a paper to the Royal Society on the "Influence of Light upon Protoplasm." They called attention to the fact, that diffused and still more direct sunlight had the power of killing putrefaction bacteria, that heat rays play no part in this action, and that the most active are the blue, violet and ultra-violet frequencies, but that the red and orange are not entirely inactive. Their experiments still further show that it did not matter whether the bacteria were damp or thoroughly dried, but that the presence of oxygen was of absolute necessity for this bactericidal effect. They were of the opinion that the action of light in these experiments upon bacteria was not to be sought in a modification of the nutritive basis, and also considered the possibility that the products of metabolism in the bacteria may be influenced by light. These facts were at first disputed by Tyndall, but they soon had abundant confirmation from all sides. The experiments of Downes and Blunt were made with any bacterial mixture of

[1]Proceedings of the Royal Society of London, Dec. 6, 1877, Vol. XXVI., p. 488, and Dec. 19, 1878, Vol. XX., p. 109.

decomposing liquids conveniently at hand, but later investigators have used pure cultures.

In 1892 Marshall Ward[1] presented a paper to the Royal Society of London, entitled "Experiments on the Action of Light on the Bacillus Anthracis." He showed the effect of light on bacilli from the Thames, and found that in all cases solar and electric-arc spectra exerted no perceptible action whatever in the infra-red, red, orange or yellow region, while all the bacteria were injured or destroyed by the rays from the blue or violet spectrum. The intervention of a thin piece of glass resulted in cutting off a large proportion of the effective rays. The most distinctive rays, i.e., those at the end of the blue and beginning of the violet, were to some extent effective, even after reflection from the inner face of a quartz plate covering the film, and the glass on which it was supported. Ward also showed that moulds and yeast cells were injured in their development and growth, a fact more recently corroborated by Bie. This former investigator goes on to say that these results evidently suggest that the naked arc light may prove to be a very efficient disinfecting agent for use in hospital wards, railway carriages and other places where the rays could be projected directly on the organisms. In this report Professor Ward stated:

"The results are as startling as they are important, for if the explanation given of the phenomena observed in the following experiments turns out to be the correct one, we stand face to face with the fact that by far the most potent factor in the purification of air and rivers of bacteria is sunlight."

Professor Ward in connection with Sir Oliver Lodge[2] exposed culture plates to the ultra-violet energy of the electric arc alone, as well as to the energy of other parts

[1]Quoted from Committee Report on Light as a Diagnostic and Therapeutic Measure by Margaret A. Cleaves, M.D., to American Electro-Therapeutic Association, Sept. 25, 26, and 27, 1894.

[2]Lectures to Medical Practitioners upon Physics, by Sir Oliver W. Lodge. Archives Roentgen Ray, June, 1904.

of the spectrum, establishing a much more powerful bactericidal action with the ultra-violet alone.

In the more recent investigations, care has been taken to consider not only the fact of the bactericidal action of light, but also the physical factors in that action. To that end the sources of light were taken into account, their intensity and the use of light filters as well. These physical factors were most carefully considered in the experiments of Bernard and Morgan to be subsequently detailed.

Theodore Geisler[1] in 1892 found no qualitative difference between sunlight and electric light, only a quantitative difference. In the course of some experiments on the typhoid bacillus he found that the most decided effect was produced by the rays from the violet end of the spectrum.

His experiments were conducted in the following manner: two cultures were sown with typhus bacilli and placed in the dark, two in the sunlight, and two placed 1 mm. from an electric arc of 1,000 candle-power.

He concluded as follows: That there is no qualitative difference between the electric arc and solar light, and that all the frequencies of the solar and the electric arc spectrum, save the red, retard the development of the typhus bacillus, and that this influence is so much the stronger the more refrangible are these frequencies, i.e., the shorter and higher their wave length.

The author has substantiated this action of the chemical frequencies, visible and invisible, as obtained from a 7-ampère water-cooled iron electrode lamp, a 5-minute application destroying them completely. The same was true of the staphylococcus pyogenes aureus.

P. A. Khmelevský,[2] of St. Petersburg, after prolonged experiments, concluded that both solar and electric light have an undoubted inhibitory influence on the growth of microbes.

[1]Centralblatt für Bakteriol. V. II., 1892.

[2]Quoted by author in 1894.

Klebs-Löffler[1] discovered that diffused light does not prevent the development of cultures of diphtheria at ordinary temperatures, or at a temperature as high as 95°F., but that sunlight arrests development, and after an exposure of several days sterilizes bouillon. This bactericidal power of light toward the bacillus of diphtheria is due almost exclusively to the rays of greatest refraction, those at the other end of the spectrum having little or no action of this kind.

There is a very extensive bibliography upon this subject, and Freund[2] refers to the following experimenters: Faligati (1), Arloing (2), Duclaux (3), Lubbert (4), Janowski (5), Santori (6), Raspe (7), Geissler (8), Kolliar (9), Dandrien (10), Chmiliewsky (11), Gaillard (12), Marshall Ward (13), Ledoux-Lebard (14), Pansini (15), d'Arsonval and Charrin (16), Roux (17), Billings and Peekham (18), Kruse (19), Koch (20), Beck and Schultz (21), Dieudonne (22), Buchner (23), v. Esmarch (24), Giunti (25), Martinaud (26), Momont (27), Wittlin (28), Richardson (29), Shickhardt (30), and Ruhemann (31). This bibliography is appended for the benefit of the reader who may not have access to Freund's book.

[1]Quoted by the author in 1894. Com. Report on Light as a Diagnostic and Therapeutic Measure Am. Electro-Therapeutic Ass., 1894.

[2]Freund, Radiotherapy, Rebman & Co.

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(4) Ref. in Raum, Zeitschr. f. Hyg., Vol. VI.
(5) Centralbl. f. Bakteriologie, Vol. VIII., p. 167.
(6) Boll. della Accad. med. d'igiene, Roma, Vol. XVI., p. 386.
(7) Einfluss des Sonnenlichtes auf Mikroben. Dissertation, Schwerin, 1891.
(8) Centralbl. f. Bakt., Vol. XI., p. 161.
(9) Ibid., Vol. XII., p. 836.
(10) Annales d'Hygiène, 1888, p. 448.
(11) Wratsch, 1892, No. 20.
(12) Thèse de Lyon, p. 396.
(13) Proceedings of the Royal Soc. of London, Vol. LII., p. 393, and Vol. LIII., p. 23.
(14) Arch. de medec. exp., etc., Ser. 1, Vol. V., p. 779.
(15) Riv. d'igiene, 1889.
(16) Arch. de physiologie norm. et patholog., Vol. VI. p. 335.
(17) Ann. de l'instit. Pasteur, 1887.
(18) Centralbl. f. Bakt., Vol. XIX., p. 244.
(19) Zeitschr. f. Hygiene, 1895, 322.
(20) Ueber bakteriologische Forschung, Berlin (Hirschwald), 1890.
(21) Zeitschr. f. Hygiene, Vol. XXIII.
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(23) Centralbl. f. Bakt., Vol. XI., p. 781, Vol. XII., p. 217, and Arch. f. Hygiene, Vol. XVII.
(24) Zeitschr. f. Hygiene, Vol. XVI.
(25) Stat. sper. agrar. ital., Vol. XVIII.
(26) Compt. rend. Acad. d. Sc., Vol. CXIII.
(27) Annales de l'instit. Pasteur, 1892.
(28) Wiener klin. Wochenschr., 1896.
(29) Transact. of the Chem. Soc., 1893.
(30) Friedreich's Blätter f. gericht. Med. 1893, p. 405.
(31) Zeitschr. f. diät. und phys. Therapie, Vol. IV.

Among the lower forms of life, especially upon bacteria, strong light has a fatal action.

The bactericidal action of light belongs to the ultra-violet end of the spectrum.

By means of an ordinary arc lamp bacteria may be killed in from 5 to 8 hours, but by means of concentrated arc light through condensing lenses of quartz, they can be killed in as many minutes (Finsen).

Both solar and the electric light, when diffused, are much less active than when concentrated, and require much longer to exert their bactericidal and disinfecting action. This action is very mild with an incandescent light as compared with the electric arc and the sun, nor is it to be regarded as a germicidal agent, although it is by no means inert, as it has abundant blue and violet frequencies, which are chemically active. Blue light of great intensity has been shown by Kaiser to have a bactericidal action. See Chapter XIV.

Below the ultra-violet then, the spectrum is not active as a direct bactericidal agent, but there is a modifying influence exerted by the chemical frequencies (blue and violet) tending to a diminution of the virulence and ultimate death of pathogenic organisms.

Dieudonne observed that direct sunlight will kill bacteria in one-half hour, diffused daylight in 6 hours, an electric arc light of 900 nominal candle-power in 8 hours, and an electric incandescent lamp in 11 hours.[1] The action of sunlight upon bacteria depends upon the season of the year, as its intensity naturally varies. The experiments of Finsen, Bang and Strebel show that concentrated sunlight checked the growth of bacteria after one minute, and caused death in 5 to 7 minutes. Concentrated arc light checked the growth after 4 to 5 minutes and killed the bacteria in from 15 to 20. Arc lights with metal electrodes and the electric spark kill micro-organisms after a few seconds, 5 to 40.

[1]Dieudonne, quoted by Freund.

The disinfectant action of light has been clearly demonstrated after the rays have penetrated clear water to a depth of at least 30 centimetres. This shows that water exposed to the sun's rays, for example, if perfectly clear and not of great depth, can be freed from pathogenic organisms. But as it has been shown by Bernard and Morgan in their experiments, that 2.5 centimetres of water is sufficient to cut off four-fifths of the rays from the middle of the ultra-violet region, in which are the active bactericidal frequencies, it follows that this disinfectant action of solar light to exposed water to a depth of 30 centimetres must be due to a penetration of the visible chemical frequencies, blue and violet.

The bactericidal effects of sunlight have been extensively studied. The evidence shows that sunlight plays an important part in nature in the disinfection or self-cleansing of rivers.[1] The water of rivers contaminated by sewage is found to become free from bacteria after having flowed for some distance. That a part of this demonstrated effect may be due to dilution, to deposit of sediment, and to absorption or decomposition of substances by plants or animals is very probable. Still the disinfection of running water is undoubtedly contributed to very largely by the chemical frequencies of sunlight. It also has an effect upon the dust of streets. This was the subject of experiment by Wittlin,[2] who showed that it was disinfected in a high degree by sunlight. The bactericidal effect of direct sunlight upon germ-containing clothes, bedclothes, etc., was tested by von Esmarch, who found that the action is confined to the exterior layers of the objects, and does not penetrate into the interior at all.

Tubercle bacilli are quickly killed by direct exposure to the solar rays, the time varying according to circumstances, from a few minutes to several hours; while the diffuse rays

[1]Prausnitz: Influence des Egouts de Munich sur l'Isar. Munich, 1889.
[2]Quoted by Freund, Radiotherapy.

will destroy these organisms in from 5 to 7 days, their virulence diminishing before their death. (Koch.)

The bactericidal effect of light is dependent on the quantity of light. It appears to have been proven by Krebs[1] that an arc lamp using 5 ampères of current as in an ordinary electric-light bath, has practically no power over the micro-organisms of the skin. In the case of arcs taking from 60 to 75 ampères, Freund[2] found that no bactericidal action took place when the rays were passed through living tissue. The ear of a black rabbit was stretched between the rays and a plate culture of staphylococcus pyogeneus aureus. The culture was placed in the incubator after an hour's exposure, but the next day was found to be covered with colonies of bacteria. The same negative result followed the experiment with the ear of a white rabbit, and also with the ear moistened with adrenalin. In all 3 cases the inflammation of the ear developed in 24 hours.

By a sufficiently prolonged exposure to the active solar rays practically all pathogenic bacteria and spores may be destroyed. "The germicidal action seems to be due partially to changes in the medium involving its contained oxygen, but chiefly to a direct action of the chemical frequencies of light."[3]

Different kinds of bacteria are differently affected, some being much more quickly affected than others. The experiments of Larsen[4] showed that the bacilli of typhus, diphtheria, plague and splenic fever have very little resisting power, while tubercle bacilli and staphylococci offer greater resistance. Light is favorable to the growth of some forms. This was observed by Engelmann in bacterium photometricum, by Gaillard in yeast and mould fungi, and by Schenk[5] in a coccus cultivated from the feces.

[1]Zeitschrift für Diät. und Physikalische Ther.
[2]Freund, Radiotherapy.
[3]The General Principles of Preventive Medicine. Prize Essay, W. Wayne Babcock.
[4]Mittheilungen aus Finsen's Med. Lichtinstitut, I., p. 89.
[5]Larsen, Engelmann, Gaillard, Schenk, quoted by Freund.

The spores and the bacilli of splenic fever offer different powers of resistance also, as shown by Arloing, who succeeded in killing the former in 2 hours' exposure to direct sun heat, while from 26—30 hours were needed for the latter.

A degree of illumination used may be insufficient for the complete checking of the development, yet may in some cases prove harmful to the formation of pigment. But in the case of other bacteria again, i.e., micrococcus ochroleucus, light is a necessary condition for this.[1] All of the experimental work shows that by the exposure to light the development of the bacteria is not only checked, but also the virulence of the micro-organisms is lessened.

For the purpose of proving in what part of the spectrum the bactericidal frequencies are to be found, science is most indebted to Vlademar Bie, Sophus Bang, Bernard and Morgan. The two former are known in connection with Finsen, being associated with him in his work.

Bie's experiments were made with the bacillus prodigiosus and the light from a 35 ampère arc at 44 to 46 volts, giving about 600 candle-power. The light was concentrated by a Finsen apparatus, and fell vertically upon the culture. Vessels with plano-parallel glass walls enclosing a layer of fluid 3 cm. in thickness were used as light filters. As absorbing media Bie used (1) a fresh 1% sulphuric acid solution of quinin with a few drops of sulphuric acid, which allows the passage of all the rays but the ultra-violet; (2) a 5% solution of chromate of potassium, letting through red to green inclusive; (3) a 1½% solution of bichromate of potassium, letting through red to green inclusive; (4) a 1½% solution of bichromate of potassium, letting through red to yellow inclusive; (5) a 1-7% solution of fuchsin, letting through red alone.

The light intensity was determined by comparing the degree of blackening of spots, produced by exposure of aristo paper to the light during definite periods of time.

[1]Freund.

Bie found as a result of these experiments that all the frequencies of the visible spectrum, and the invisible chemical frequencies or ultra-violet (the infra-red were not examined), in an increasing ratio from red onward, checked bacterial development. The action was found to increase with the ratio of refrangibility, but was especially marked in the blue, violet and ultra-violet frequencies. It was only after prolonged illumination that a bactericidal action was obtained from the red, orange and green frequencies. It was not until an exposure of 1½ hours had been made with light that even the faintest perceptible retardation of growth was observed from the action of pure red light.

The experiments of Sophus Bang were conducted with the greatest care. He took into account all the conditions to be noted with regard to light-action, the strength of light used, the distance of the object from the ray source, the kind of rays passing the filters and the amount passing through, the percentage of light penetrating through the bacteria (taking into account the absorption and refraction of the light through the containing vessel and the culture medium).

Everything was so arranged in making these experiments that the beam of light should meet with as few obstacles as possible on its way from the light source to the object. The reflecting planes were as few and as simple, and the absorption and refraction as slight as possible; an even temperature was maintained, and measures were adopted for varying the strength of the light according to the gradation desired. In his experiments Bang used an apparatus in which the bacteria culture was spread out for examination in the thinnest possible layer, e.g., as a suspended drop on thin quartz plate. This quartz plate was used as the lid of a "moist chamber," which, in turn, was fixed in a box filled with water of an even temperature, kept constantly flowing by a paddle wheel. The light was then admitted through a quartz window in the side of the box, and its intensity and direction of incidence exactly estimated. Under these conditions Bang reached the conclusion

that under the influence of light at a distance of 28 cm. from a 35-ampère 50-volt electric arc, at an angle of 45° to the axis of the carbon, after a part of the heat rays had been kept back by a layer of water 25 mm. in thickness between quartz plates, and at a temperature of 30°C., a 3-hours prodigiosus broth culture in a pendant drop is sterilized in about one minute, a 10 to 15 hours culture in from 3 to 5 minutes. The light acts more quickly at 45°C. than at 30°C., sterilizing a 3 hours culture in about half a minute.

The older the culture, therefore, the more resistant it is to the action of the light, and further with increase of temperature the bactericidal action from light increases.[1]

More recently two English physicists, Bernard and Morgan, at the suggestion of Dr. Allen Macfayden have conducted a series of very careful experiments to determine (1) to what portion of the ultra-violet spectrum is the bactericidal action due, and (2) is it a primary or a secondary effect due to the reaction established in the tissues.

This well-known action of the higher and shorter frequencies of light vibrations, or light without heat, to destroy micro-organisms without the body, is axiomatic. This point was first covered by the experiments and verified at every turn. That organisms inside of the living body were destructively acted upon by light vibrations was regarded as a matter of considerable doubt. Just here it may be well to note in passing that the bactericidal action attributed to radio-active substances, to the X ray, to high-frequency currents or to other forms of electricity, unless in the polar action of the continuous current, anodal, by reason of its intense acidity and free oxygen, cannot in any instance be regarded as an immediate lethal effect upon the micro-organisms within the tissues, but rather as an inhibitory action, while the reaction established in the tissues through the local or general expenditure of one or the other forms of energy,

[1]For detailed description of Bie's and Bang's experiments the author is indebted to the English translation of Freund's Radiotherapy, pp. 406, 407, 408.

renders them an unfit habitation for living micro-organisms. It becomes simply a question of the survival of the fittest. And more, there is an action upon the oxygenating power of the blood-stream which tends to a removal of the detritus loading the vascular system, and at the same time the products of cell necrosis. That there is an effect upon the products of bacterial metabolism as suggested by Downes and Blunt seems very certain, tending to their removal, an effect of more importance even than the actual destruction of the bacilli.

By their experiments Bernard and Morgan[1] found that light was powerless to destroy bacteria in those cases where its rays were made to pass through any organic substance before impinging upon the bacteria, and even the thinnest film of agar served to protect the bacterial cultures. Much less can the bactericidal rays penetrate living or dead tissue under the ordinary conditions of experiment. This statement they proved in the following manner:

The light from an automatic arc lamp, that is, a lamp in which the carbons were kept at a suitable distance by means of a clock-work arrangement, was allowed to pass through a metal cylinder through which water constantly circulated to eliminate heat, and which was closed at each end with a disc of quartz. An agar plate was thickly inoculated with an active culture of bacillus coli communis, and exposed to the light directly after inoculation, and then incubated for 24 hours or longer at 37°C. The light was only permitted to fall on a portion of the plate in order that the organisms should grow naturally on the other part, and thus serve as a control. A current of 7 ampères was used at a distance of 10 cm. from the arc.

In 11 seconds the comparative number of surface colonies was greatly reduced, but those in the depths were unaffected. After an exposure of 2 hours and under the same conditions, the deep colonies were still unaffected.

* The Physical Factors in Phototherapy. By J. E. Bernard and H. D. R. Morgan. British Medical Journal, Nov. 14, 1903.

Again a portion of the human skin, in one instance the cortical layer, in another the subcutaneous cellular tissue, was stretched over the quartz disc of the apparatus covering it entirely. An active culture of bacillus coli communis was then placed by means of a sterilized brush, upon an agar plate; this in turn was placed so that the light from the arc fell directly upon it after passing through the cooling chamber and the human skin. After a 2 hours exposure no effect was produced on the bacilli, as on incubating the plate at 37°C. for 24 hours, the resulting growth was found to be equally vigorous over the entire surface of the plate.

The experiment was repeated both with a living and with a dead frog's foot, and with equally negative results. The light passing at the side of the frog's foot produced a destruction of almost all the surface bacilli, while those protected by the semi-transparent webbing of the foot grew normally. (See Fig. 4.) The reason why all the colonies on the surface of the agar are not destroyed even where the undisturbed light falls upon them is still undetermined. It is perhaps possible that some few of the organisms during the process of inoculation have been introduced under the surface, and not being strictly superficial, are protected by an overlying absorbent film of agar.

From these experiments they were led to the conclusion that the bactericidal rays being non-penetrative, the therapeutic effect of light might possibly be due to the reaction produced in the tissues by the light rather than by the direct bactericidal action of the rays themselves.

A series of experiments were then made to differentiate, if possible, between the frequencies which are bactercidal and the frequencies of vibration which excite a reaction in living tissue. In this at the time of their report they had only been partially successful.

In order to discover the most active bactericidal rays, a continuous-current hand-fed arc was used, and the spectrum, as transmitted by a spectroscope with quartz lenses and

prisms, was allowed to fall on superficially inoculated plates. A subsidiary quartz lens of 18-inch focus was used to project the image of the arc on the slit of the spectroscope, thus obtaining the spectrum of carbon in the same manner as for photography, the superficially inoculated bacterial plate being used instead of a photographic plate.

It was found that the bactericidal effect was entirely confined to the ultra-violet portion, as shown in Fig. 5. The line shown at *V* is where the ultimate edge of the visible violet fell, the red in the spectrum falling at the extreme edge of the plate. The bactericidal lines are seen to begin at 2.5 cm. from the edge of the visible violet, and to extend from that point for 1.8 cm. into the ultra-violet. The photograph of the plate showed that the ultra-violet extended 1.5 cm. beyond this. No effect whatever was obtained with any other portion of the spectrum after 2 hours' exposure, and with the slit of the spectroscope open to an extent that would have been regarded as inadmissible in photography. The active bactericidal radiations have thus been accurately determined and lie in that portion of the spectrum between $\lambda =$ (wave lengths) 3,287 and 2,265, or in about the middle third of the ultra-violet region as seen in a photograph of the spectrum of carbon. Neither the extreme ultra-violet nor those nearest to the visible violet region appeared to be active. The affected portion of the bactericidal plates corresponded to a photograph taken of this portion of the spectrum, and it was possible to identify the nearly sterile lines on the plate with those known to exist in the ultra-violet spectrum of carbon.

The conclusion is, therefore, reached that relatively the action of the other portions of the spectrum is negligible with the activity of this portion, although when using white light it is possible that there is a slight action extending over the whole spectrum. This conclusion affords, then, a physical basis for similarity of therapeutic effect from widely different adjustments of arc-light mechanisms, giving good

Fig. 4.—Experiment with Dead Frog's Foot.

Fig. 5.—Plate showing effect of ultra-violet rays upon growth of bacteria. V, ultimate edge of visible violet rays, to the right of which is the visible spectrum, and to the left the ultra-violet.

values in white light, but at the same time it substantiates the use of mechanisms arranged to give the maximum of the visible and invisible ultra-violet frequencies.

A third series of experiments was then made to determine which rays were active in exciting reaction on the part of the tissues. These, while suggestive, are not yet regarded as conclusive.

The shaved skin of a rabbit, anesthetized to secure absolute quiet, was subjected to the spectrum, with the same spectroscopic arrangement as before, and no effect whatever was produced after an exposure of two and three-quarter hours, with a current of 25 ampères. Guinea-pigs, white rats, frogs, and even a human arm were similarly subjected to the same spectrum, but with absolutely no evidence of tissue reaction whatever.

An additional experiment seemed to show that the rays exciting this reaction exist somewhere in the ultra-violet region. A rabbit shaven on both sides of its body was subjected to the action of the light 25 ampères of current) passing through the water-circulating apparatus. Contact was made with the quartz disc on one side for 5 minutes. Then the other side was exposed in the same fashion, save that a sheet of glass was inserted between the water-cooling apparatus and the skin. The second exposure lasted an hour and was made with a current of 25 ampères. On the following morning, on the side exposed to the rays through glass for an hour, absolutely no effect had been produced on the skin, while on the side exposed but 5 minutes through quartz, and without the intervention of glass there was a well-marked redness.

This, the author has clearly substantiated in the therapeutic uses of apparatus arranged with (1) glass plates or discs, (2) quartz discs, and also in experiments made upon culture plates, the bactericidal effect being active with the quartz, absent with the glass. The well-known transparency of quartz to the extremely short and high frequencies, ultra-violet, and their loss or absorption upon the interposition of

glass, accounts for the results obtained both experimentally and therapeutically.

All rays of the spectrum, save the greater part of the ultra-violet, readily penetrate glass, and any effect obtained with apparatus containing lenses or globes of glass is evidently due to the feeble penetration of a few of the frequencies on the extreme edge of the violet as it merges into the ultra-violet region. To obtain the maximum effect of ultra-violet frequencies when combined with blue-violet is to secure the maximum result in the treatment of such pathologies as lupus vulgaris, as has been done by Finsen.

It is then clearly proven that the frequencies which excite tissue reaction are to be found in the ultra-violet region, but it is not yet accurately determined in just what portion of the ultra-violet spectrum they are located.

In view of the results obtained with the spectroscope on bacteria culture plates Bernard and Morgan made experiments additionally with the spectra of various metals, such as iron, cadmium, silver and aluminum. The results agreed entirely with those obtained from the carbon spectra, save that the bacterial action was intensified in proportion to the number and intensity of the lines or frequencies in the bactericidal region of the spectrum. From the number of the lines in the spectrum of iron it was concluded that an electrode composed entirely or partly of iron should be found more actively bactericidal than a carbon one. This proved to be the case. The form of electrode found to be most convenient in these experiments was that in which, in the case of the positive electrode, the soft carbon core was removed and in its place was substituted a mixture consisting of the particular metal it was desired to use, with sufficient carbon in the form of sugar to prevent the core from dropping out when in use. The negative electrode was unchanged. The respective electrodes were then fitted into the arc lamp, and the bactericidal power tested on a hanging drop specimen of bacillus coli communis. The slide on which the hanging drop cover slip was placed was composed of quartz, in order that the ultra-violet frequencies might be intercepted as little as possible. The hanging drop thus mounted was placed on the water-circulating apparatus, the light from the arc being projected from below upwards on to the hanging drop. In making these various electrodes in the arc lamp, it was found that the time required to destroy the bacilli, with, in each case, a current of 11 ampères, at a distance of 10 cm. from the arc varied as follows:

Ordinary carbons	30	minutes.
Carbons charged with silver	30	"
Carbons " " iron	15	"
Carbons " " cadmium	15	"
Carbons " " aluminum	25	"

To ascertain whether the bacilli were killed or not the hanging drop was examined from time to time under the microscope. When all the motility had ceased, the cover slip with the hanging drop upon it was dropped into a tube of peptone beef broth. This tube was then incubated at a temperature of 37°C. for some days to see if any growth resulted.

From the table above it will be seen that carbon electrodes charged with iron and cadmium have twice the bactericidal effect of ordinary carbons; and the cadmium carbons seem to be preferable to the iron ones, as they burn more steadily in the arc lamp. There is a good deal of evidence pointing to a bactericidal power on the part of the blue and violet frequencies, almost equal to the ultra-violet, but these spectroscopic experiments, as well as the following, indicate that such is not the case.

An ordinary glass slide was used, though the light from the arc was passed after having been cooled by transmission through a water-circulating apparatus. The electrodes used were charged with cadmium. Although the motility of the bacilli was stopped after an exposure of 55 minutes, they were not killed even after an exposure of an hour and 20 minutes, that is, in a period five times (a

little more than five times—15 minutes against 80) longer than was necessary to kill the organism when the quartz slide was used. This shows that the visible chemical frequencies, the blue, indigo, and violet, which readily pass through the glass are not bactericidal under these conditions, or only slightly so. The glass intercepted the ultra-violet frequencies, preventing, therefore, their bactericidal power. Comparison was also made between the results obtained with the hanging drop culture, as just described, and those obtained from superficially inoculated agar plates, under the same conditions, and it was found that although half an hour was required to kill the bacillus coli communis in the hanging drop exposed to the light, the same result was obtained on an agar plate in 5 minutes. Or, in other words, six times as long is required to destroy the bacilli when they are suspended in a fluid medium.

This observation led to still another experiment, viz., to determine what proportion of the bactericidal frequencies is absorbed by the thickness of water they have to traverse in the water-circulating lamps employed therapeutically.

To determine the influence of this factor the following experiment was made: The water-circulating apparatus, as already described, consisted of a short brass tube with an inlet and outlet for water, the ends being closed with a quartz disc. The distance between the quartz discs was 2.5 cm., and represented the depth of water to be traversed by the light. An extended image of the arc was projected on to an agar plate, which had been superficially inoculated with the colon bacillus. The arc image was obtained by means of a pinhole in the metal plate interposed between the light source and the agar film. A projected image of the positive and negative poles and of the image of the arc resulted. They found, however, that under these conditions the loss of light was so considerable that a very long exposure became necessary, and, therefore, substituted for the pinhole a metal plate with a slit in it. The slit was less in width than the length of the arc itself, and was placed about 3 cm. from

the arc, with the direction of slit at right angles to the axis of the carbons.

An image was thus obtained which was in reality made up of a number of superimposed images similar to those obtained with the pinhole arrangement. On the agar plate the image was seen as a central broad violet band, above which was the narrow white band of light projected from the negative carbon, and below the brighter white band projected from the positive electrode.

As heat might be a possible disturbing factor, the images from the electrodes were eliminated from the experiments, only the effects of the broad violet band from the arc itself being considered.

Although they had no absorbing medium other than air between the arc and the agar plate, the light was almost free from heat rays, any possible rise of temperature being quite negligible. Inoculated plates were then exposed in the first instance without any heat-absorbing apparatus, and subsequently with a water-circulating apparatus interposed between the slit and the inoculated agar film.

It was found that an exposure of 5 minutes without the water-circulating apparatus had a greater bactericidal effect at a point of incidence of the light than a 25 minutes exposure with it. In other words, that the light on passing through 2.5 cm. of water lost four-fifths of its bactericidal power. This result they had hardly anticipated in view of the researches of Hartley and others, in which water was shown to be but slightly absorbent either to visible or ultra-violet radiations.

The loss of bactericidal power may, however, be attributed to general rather than to selective absorption. The quartz may be regarded as negligible, as its transparency is well known, and they subsequently found that it transmits the bactericidal radiations practically without any loss of absorption. It would, therefore, appear that in photo-therapeutics the generally used water-cooling appliance might well be dispensed with if the heat could be eliminated by

other means, and assuming that the directly bactericidal rays are the only essential ones, which at present is by no means certain.

The next experiment was to determine whether, when using the electric arc, the effect is in any way a function of any particular current. It was well known that the efficiency of an arc as a source of light increases as the current is increased. The ratio of light production is approximately as follows, the standard in this case being an efficient type of oil lamp:

7 ampères	39	15 ampères	117
10 "	75	20 "	160

"On exposing bacterial plates in the above-inversed ratios we found that the action was exactly proportionate to the light produced, a current 10 ampères having approximately double the bactericidal effects of a current 7 ampères and so on. This was tested carefully up to 25 ampères with unvarying results, showing that the action is exactly proportionate to the light efficiency."

While the colon bacillus was used principally, Bernard and Morgan also employed the following organisms with similar results: bacillus prodigiosus, bacillus subtilis, micrococcus tetragenus, staphylococcus aureus and bacillus tuberculosis.

These experiments conclusively establish that while quartz transmits the bactericidal frequencies without any absorption, quartz used in connection with water-cooling apparatus is much less active, as a part of the active frequencies are absorbed by the water. The best therapeutic effect has been obtained by the author from using the source of light; (1) in general conditions all the radiant energies of the arc, (2) in local lesions direct from the arc through a compressing lens of quartz only, without the intervention of water.

Now that the frequencies which excite tissue reaction are so exactly located in the spectrum and the bactericidal region is definitely known, it will be possible to have light mechanisms so arranged as to give the maximum effect. Then it will be a question of administering the active principle of light energy, with the precision of drug therapy.

This work of Bernard and Morgan, although substantiating the work of Finsen and many other observers, is the first to definitely locate the active bactericidal frequencies. It will go far toward placing the therapeutic use of light energy on an absolutely scientific basis, as against its somewhat empirical use as still practised to-day. Clinical work points also with unerring fidelity to the need of a source of light energy rich in chemical frequencies, ultra-violet especially, where it is desired to excite tissue reaction by a localized application.

The question of bactericidal action is not the paramount one, but it is the ability of the same frequencies (ultra-violet) to excite intense tissue reaction upon which therapeutic results depend.

The frequencies of the red and green regions of the spectrum are neutral, and some observers have appeared to find them favorable to the growth of bacteria. All the evidence, however, places the bactericidal activity at the end of the spectrum most intensely chemical in its action, viz., the more refrangible blue, violet and ultra-violet frequencies, while the most recent and only spectroscopic experiments exactly locate them in the middle third of the ultra-violet region.

Sensitization of Bacteria.—As the gelatin bromide plates grasp the waves of short and high frequency with which space is filled by the millions and hold their energy fast, in particles of silver, so recent investigators[1] have endeavored to utilize the energy of longer and slower wave lengths, green, yellow, and even red, by rendering the tissues *sensitive* with suitable substances just as is the bromide plate.

All accumulated evidence shows that the bactericidal fre-

[1]Schlesische Gesellschaft für vaterländische Kultur by Professor Neisser and Dr. Halberstadter, Section of Medicine, Deutsche Medicinische Wochenschrift, Feb. 18, 1904. Reviewed by Stephane Leduc, Archives d'électricité.

quencies and those exciting tissue reaction, i.e., blue, violet and ultra-violet, or the most refrangible of the spectrum, possess the least penetrative power, while the less refrangible frequencies, green, yellow and red, have the greatest penetrative power.

The question arose in the mind of Dreyer,[1] of Copenhagen, as to whether living tissue does not comport itself as does a photographic plate, and if the same substances used for the latter will not act upon the former and render them sensitive to the green, yellow and red frequencies of the spectrum.

The following experiments were made by Dreyer: cultures of prodigiosus, and also of the infusoria nassulo were placed in a small quartz chamber, cooled by a circulation of water, the liquid was sensitized by a 1/5000 solution of erythrosin, which by itself is without any action upon infusoria or bacteria. The concentrated light of a 30 ampère arc at 50 volts pressure through a quartz filter was utilized. To study the action of the different frequencies of the spectrum, he filtered the light successively through glass, solution of sulphate of nickel, of chromate of potassium, and of bichromate of potassium. The results are contained in the following table:

Filter	Rays acting	Time after which are dead			
		Infusoria		Bacteria	
		Sensitized	Normal	Sensitized	Normal
Quartz . . .	The whole spectrum including the ultra-violet .	10″	100″	60″	80″
Glass	The visible spectrum	10″	9′	10′	10′
Sulphate of nickel, 5% .	Red, orange, yellow, green and blue	10″	13′	10′	10′
Chromate of potassium .	Red, orange, yellow, and green .	10″	70′	15′	More than 4 hours
Bichromate of potassium .	Red, orange, yellow	10″	110′	25′	More than 9 hours

[1]Mitteilungen aus Finsen's Med. Lichtinstitut—1904, Heft VII.

The action of the less refrangible frequencies of the spectrum upon sensitized infusoria and bacteria is very strikingly shown by the results of Dreyer's experiments.

A 30-minute exposure of a culture of prodigiosus to the quartz spectrum of a lamp 26 ampères, the non-sensitized bacteria were only killed in the ultra-violet; while in the cultures sensitized by erythrosin death is produced by the orange and yellow frequencies also. These have been rendered equally active with the ultra-violet by reason of the erythrosin solution in which the cultures were placed, and which has served to store the energy of the orange and yellow frequencies. In the doing of this a chemical action takes place just as with the silver of the bromide plate in photography, an action which is disastrous to the integrity of the micro-organisms. Dreyer found that the animal tissues were also capable of being rendered sensitive to the action of the orange and yellow frequencies. This he established experimentally upon tadpoles, rabbits, and upon the human skin. With concentrated light acting through 1.25 mm. of skin Dreyer was able to kill in 32 seconds sensitized infusoria; but when non-sensitized under the same conditions death only ensued after 60 minutes.

Sensitized bacteria treated in the same manner died after 20 minutes, while the non-sensitized were still alive after 11 hours.

Thus it is shown experimentally that both bacteria and the tissues can by being covered with suitable media be rendered as sensitive to the longer, slower, less refrangible and more penetrating frequencies as they are to the very little penetrating frequencies of the ultra-violet. This action, according to Leduc,[1] does not in any sense depend upon fluorescence; for there are sensitizing substances which are not fluorescent, and fluorescent substances which are not sensitizing.

There are, for example, fluorescent substances which

[1]Ibid.

absorb energy of radiation at the same degree of erythrosin, but they are not sensitizing—i.e., they absorb the energy of the more refrangible frequencies, but do not emit them at a lower or less refrangible degree of radiation. On the contrary they fix or store the energy. This means work done—just as surely as the impression made upon the photographic plate by the silver bromide, nor is there any formation of toxic material by the action of light upon the sensitized liquids. If such a liquid is exposed to the light first and the infusoria or bacteria placed therein, no lethal action follows.

The experiments reported by Dr. Halberstadter confirm at every point the researches of Dreyer, not only upon the sensitized infusoria and bacteria but upon living tissue as well. The direct physical action of the bactericidal or ultra-violet frequencies upon bacteria is due to their short lengths and high frequency, i.e., the inconceivable rates at which they swing to and fro in their own free paths of oscillation. In so doing they have the power to agitate little things which appear in their path, such as molecules. By the profound agitation to which the bacteria are subjected by these frequencies, the death of the germ is assumed to result. It seems very probable that by this agitation they are worried very much in the same fashion as the small animal, mouse or rat, is when shaken to death by a dog or cat. This physical agitation in turn gives rise to a chemical process which insures the death of the bacteria.

Mechanical Agitation Destructive to Germs.—Mechanical agitation of germs is destructive to them. The Lancet[1] cites an instance where bacterial cultures were allowed to stand in the engine room of a large manufactory where there were incessant vibrations from the strokes of the engine. After four days the germs were destroyed and did not appear when the water was set in a quiet place. It is reported that Dr. S. J. Meltzer[2] has demonstrated that incessant vibrations of the stroke of an engine and violent shocks

[1]London Lancet, Feb., 1903.
[2]The Sun, Feb. 14, 1904.

are destructive of germ life. He found that the number of germs in the agitated fluid in no instance amounted to as much as one-tenth of those in the unshaken samples. It was also observed that the restriction in production increased with the duration of the treatment and that when the treatment was applied for a sufficient length of time the liquid could be freed from bacilli. The complete annihilation of the germs was accomplished in 10 hours of agitation, when sterilized glass beads were added to the culture.

Different organisms were found to have different degrees of resistance, so that it was possible to eliminate them successively from a solution by regulating the shaking process. The cells thus split up did not form any visible debris, but resolved themselves into a fine powder, which offered no distinguishing features under the microscope. Because of this it was concluded that there was in no sense a mechanical disruption of the cell, but that the effect was due to a chemical action.

From the physical point of view, the energy of oscillating light corpuscles is given up in the non-thermal mechanical agitation to the molecules, and this in partly atomic agitation or chemical change and the rest in heat or vibrations of the molecule; now if the molecular structure of the bacilli is unduly agitated by the swing of the oscillating light corpuscles, the ultra-violet frequencies, the energy given up to them must be of such a nature as to result in atomic agitation or chemical change which involves the giving up of their contained oxygen, so necessary to continued vitality.

In the living tissue while a direct lethal effect cannot be produced upon them by reason of their environment the atomic agitation would undoubtedly interfere with their vitality, and by reason of a chemical change. It would seem from experimental data and clinical observation that the same frequencies of light energy which unduly agitate bacilli, act as a physiological stimulus to the red blood corpuscles, increasing their oxygen-carrying capacity and therefore the oxidative processes of the entire organism. A certain vibra-

tional activity is necessary to life, still another to the maintenance of health, while a third or greater degree is destructive of life. For example, in the phenomenon of heat we have a vibrational activity—a mode of motion, and yet "a few degrees change in temperature either way will end the evanescent, fleeting, unstable and feeble thing or entity—life which was the last to appear in the midst of the stupendous cosmic war of matter and energy, and will be the first to vanish."[1] And the concentrated vibrational activity of the ultra-violet end of the spectrum, while borne in therapeutic doses by the higher organism, is fatal to the life of the lower.

This destructive action of light energy upon micro-organisms is assumed to be (1) on the plasma of the bacteria directly and (2) at the same time to be indirectly injurious to the nutritive basis, by producing a photo-chemical change. In other words there has been expended an energy, capable of establishing chemical change, which influences not only the nutritive basis, but also normal physiological action, all of which tends to the rendering of bacterial toxins inert and the removal of the detritus.

It was observed by Kruse[2] that by subjecting sterile nutritive bases to light, complex chemical bodies (peptones) were formed which checked development.

Richardson[2] proved that in fresh urine under the influence of direct illumination, peroxide of hydrogen is formed, which is decomposed by the bacteria, the latter being killed by the liberated oxygen. Dieudonne showed that through the chemical action of light upon water, peroxide of hydrogen is formed, most freely in the upper layers. As is well known, this compound is strongly antiseptic.

Bactericidal action is very largely diminished under exposure to light when oxygen is excluded, as evidenced by the experiments of Dieudonne, Tizzoni and Cattani.[3]

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[1]Larkin: Radiant Energy.
[2]Freund: Radiotherapy.
[3]Arch. f. Exper. Pathologie und Pharmakologie, Vol. XXVIII., p. 54, also Freund.

The explanation of this lies in the fact that peroxide of hydrogen cannot be formed under these conditions.

The most important factor in the human organism the author believes is to be found in the effect of the light energy upon the nutritive bases of bactericidal growths *pari passu* with its physiological action upon the entire blood stream. This action is characterized by an increase in the amount of oxygen, which experimental data shows to be so prejudicial to the well being of micro-organisms.

Outside of the living organism there is a direct injury to the protoplasm. Dried spores from all nutritive material, as both Ward and Kruse have shown, are killed by sunlight.

The movement of bacteria is also influenced by the action of light as well as their development and growth, both of which are checked.

Winogradsky[1] and Beijerinck[2] found that sulphur bacteria and the chromogenic bacteria always collect at the lightest spot, and they are thus positively phototaxic. This action is considered more at length under the action of light energy upon the elementary forms of light.

It is not only a generally accepted fact that light lessens the receptivity of an organism to living bacteria and to bacterial poisons, but the subject has been investigated experimentally demonstrating its truth by Kondratjen, Gebhard and Jousset.

Baeder,[3] who investigated this point with great care, considered it an open question.

Summary.—(1) Light energy is then not only a bactericidal agent of considerable power, but (2) the action is due to the more intensely chemical frequencies blue, indigo, violet and ultra-violet; while (3) there is no bacterial species which can resist the power of light if the light be intense

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[1]Zur Morphologie und Physiologie der Schwefelbakterien. Quoted by Freund.
[2]Centralblatt f. Bakteriologie, Vol. XIV., p. 844. Quoted by Freund.
[3]Quoted by Freund.

enough, sufficiently concentrated and exposed for a sufficient length of time.

From the chemical point of view the bactericidal power of light energy is a phenomenon of oxidation. For its successful action the presence of oxygen is necessary.

The Production of Light by Micro-Organisms.—It is a matter of common knowledge that certain organic substances, meat and fish, for example, especially salt-water fish, when the process of decomposition is first established, give off a more or less phosphorescent light, which is naturally most plainly visible in the dark.

Pflüger[1] was the first to observe that this peculiar phenomenon was an expression of the activity of micro-organisms. Since then Ludwig,[2] Fischer,[3] Beijernick,[4] Katz,[5] Giard,[6] and others have made pure cultures, and described a great number of photogenic bacteria. In this connection Fischer pointed out that even the ignis fatuus is to be explained as a bacterial phenomenon.[7]

The intensity of the light given out by the different bacteria varies greatly: the color also may differ, being white, bluish or greenish. Fischer found upon spectroscopic examination, in the case of one bacterial species, a continuous spectrum from the D-line to slightly beyond the G-line with a maximum intensity between G and F. The strength and extent of the ignis fatuus in tropical waters is a matter of common observation and description. The phosphorescence of micro-organisms may be so great as to permit of telling the time of day; while photographs of cultures have been taken by the light produced by themselves.

[1] Pflüger's Archives f. d. Gesamte Physiologie, Bd. X., s. 275 und Bd. XI., s. 222.
[2] Zeitschr. f. Mikroskopie, I.
[3] Zeitschr. f. Hygiene u. Infektionskrankh., II. Centralblatt f. Bakteriologie, III.
[4] Ref. in Koch's Jahresber. 1890, s. 180.
[5] Centralblatt für Bakteriologie, IX.
[6] Ref. in Centralblatt f. Bakteriologie, VI.
[7] These lights can, however, also be produced by other photogenic organisms, for example, by Peridinia.

Bacterial Lamps.—In this connection it cannot fail to interest the reader to quote from Molisch's[1] communication to the Vienna Academy of Sciences in reference to the photographic and illuminating power of micro-organisms in which he said he had been able to photograph phosphorescent cultures of bacteria after an exposure of 5 minutes, by their own light. In order to photograph other objects by means of this bacterial light, he constructed a special bacterial lamp. This consists of a large flask, whose interior is lined with salt-peptone-gelatin, previously inoculated with bacteria. On the second day following the inoculation the lamps begin to glow with a beautiful bluish-green light, due to the phosphorescent colonies growing within. These living lamps have the property of shining with undiminished intensity for two or three weeks, and then gradually diminishing in strength. Their light is sufficient to permit one to recognize the face of a person standing two yards away, to tell the time, to read a thermometer, or even large-size print. In view of the freedom from danger of such a cold light, its use in mining operations or in powder magazines may become of importance. Organic light, particularly the rays emanating from glowing insects, such as the so-called glowworm, has been made the subject of many investigations, and it was even asserted that this light has the properties of the Roentgen rays. Molisch, however, proved this view to be erroneous, as bacterial light acts just like ordinary light.

The Free Access of Oxygen Necessary for the Phosphorescence of Bacteria.—Of first importance among the necessary conditions for bacterial phosphorescence is the free access of oxygen. If the culture be in a solid medium only the upper layers are illuminated while a fluid medium on the contrary by shaking with air may be made luminous throughout its whole extent.

[1] The N. Y. Sun, March 15, 1903, and the International Med. Magazine, Oct., 1903.

The Influence of Temperature in the Phosphorescence of Bacteria.—This phosphorescence is influenced by the surrounding temperature. If very high or very low the fluorescence is prevented, even though the bacteria continue to live. The limits within which they live are wide, but dependent amongst other things upon the temperature.

Forster[1] found that a pure culture of a salt-water bacterium retained its power of light production and reproduction at 0°. Tollhausen[2] succeeded in reducing a culture of photogenic bacteria to —12° without the complete cessation of phosphorescence.

The Necessity for the Presence of NaCl to Insure Phosphorescence of Bacteria.—It has been shown by various experimenters, that all the light-giving bacteria require quite a high percentage of NaCl in the culture medium in order to be able to produce light. The water of the sea is, therefore, particularly suitable for the preparation of the different media.

Two theories have been adduced with regard to the light production of bacteria:

1. The production of light is a direct function of living protoplasm, and, therefore, just as inseparable from it as heat production.

2. The living cell produces and gives off a substance (photogen), which outside the cell is luminous.

Dubois[3] claims to have found such a photogen even in crystalline form, and Ludwig[4] asserts that, in the case of the micrococcus pfluegeri, it is not the colonies themselves but the products of metabolism, which give off light. All other researches with regard to photogen have led to negative results, and the theory mentioned under 2 can, therefore, not be considered as proven.

In general it may be said that light has no effect upon

[1]Centralbl. f. Bakteriologie, II. s. 337.
[2]Untersuchungen über Bakt. phosphorescens Fischer, Diss. Würzburg, 1889.
[3]Comptes Rendus de l'Academie des Sciences, Bd. CVII., s. 502.
[4]Centralbl. f. Bakteriologie, Bd. II., s. 40.

the phosphorescing power of bacteria, only Dubois[1] mentions a diminution in light production in bacteria that have been exposed to light for several days. The fact that the ignis fatuus can take on such extreme forms in the tropics, even when the sky is cloudless for days, would indicate that at least one form of light-producing bacteria possesses a comparatively great resistance to sunlight. A study of the action of concentrated electric light on these forms would be interesting.

The Action of Light on Vaccine, on Bacteria, Toxins, Enzymes, etc.—Finsen and Dreyer[2] have experimentally shown that light, and especially the ultra-violet rays, can weaken or destroy smallpox vaccine. The vaccine was placed in drops on plates of rock crystal and exposed to concentrated light from an electric arc light of 25 ampères, 50 volts; the action of the heat was hindered by sprinkling with cold water, and the results were found by vaccinating children with it thereafter. An exposure to light lasting more than 10 seconds showed plainly a loss of strength in the vaccine, while an exposure of about 200 seconds was required to render the vaccine incapable of producing pustules. A prodigiosus culture was devitalized by the same illumination inside of 40 seconds. With illumination through blue or clear glass, which kept back the ultra-violet rays, the destruction of the vaccine was accomplished only after 15-20 minutes.

On the toxins of bacteria and all enzymes, which so far have been examined in this respect, light exerts a very destructive action.

Tizzoni and Cattani[3] found that long-continued action of sunlight not only is able to destroy the tetanus bacillus, but also to render inert the tetanus toxins. This destruction took place most rapidly, when there was access to the oxygen of the air. These experiments were verified by those

[1]Loc. cit.
[2]Mitteilungen aus Finsen's Med. Lichtinstitut, 1903, Heft III.
[3]Archives f. Exper. Pathologie, 1890, XXVII.

of Fermis and Cellis,[1] according to which the tetanus poison completely loses its toxic action after exposure to sunlight for several days. Later experiments showed a similar conduct with regard to the toxins of other bacteria.

With regard to enzymes, Downes and Blunt,[2] who also included this subject in their extensive and admirable researches, found that invertin was destroyed in sunlight, so that it lost its power to convert cane sugar.

Green[3] has shown by unusually delicate experiments the destructive action of light on the diastatic enzymes occurring in the leaves of plants. This action is derived from the ultra-violet rays, while the blue, and especially the red rays, possess a favorable action, in so far as they are able to convert the zymogen of the diastase into an active form.

Schmidt-Nielsen[4] undertook lately in the above-mentioned laboratory a series of experiments with regard to the action of light on chymosin (rennet). He exposed it to light in small chambers whose walls consisted of quartz, and used as a standard of measurement (for the action of the light) the time required by 0.1 cm.^{3} enzyme solution to coagulate 10 cm.^{3} milk at a temperature of 37°. Non-concentrated electric light and sunlight had very little influence on the chymosin, while a very short exposure to concentrated electric light lengthened the coagulation time quite materially. The action was ascribed to the ultra-violet rays, and the insertion of a piece of clear glass was sufficient to prevent this action. When the chymosin, after illumination, was kept in the dark an after effect was plainly noticed after one day.

An attempt to make the enzyme sensitive to the rays which can be seen, by the addition of a sensitizer (erythrosin) gave negative results. As above mentioned, however,

[1]Ref. in Centralbl. f. Bakteriologie, 1892, XII., No. 18.
[2]Proceedings of the Royal Society of London, Vol. XXVIII., s. 205.
[3]Philosophical Transactions of the Royal Society of London, 1897, Vol. CLXXXVIII., s. 167-190.
[4]Mitteilungen aus Finsen's Med. Lichtinstitut, 1904, Heft IX.

Tappeiner[1] showed that enzymes as well as toxins can be sensitized[2] by the use of eosin and magdala red.

On the chymosinogen—the zymogen or proenzyme of chymosin—the ultra-violet waves exerted a deleterious action similar to that on rennet, and contrary to Green's above-mentioned experiment Schmidt-Nielsen found that the red rays did not possess any active influence. Ordinary blood serum has the power of preventing the activity of enzymes, the active substance here—antichymosin—is also weakened by the action of light.

The Action of Light Energy upon Hygiene and Sanitation.—From this array of evidence a practical deduction is to be made, viz., the influence of light in hygiene and sanitation. It is a perfectly well-known fact but not one that is lived up to even by the profession. The author would recall the experiment of Momont with the blotting paper saturated with charbon blood, the experiment of von Esmarch as to the extent of the action of light energy in destroying micro-organisms contained in bedclothing, of the purification of water by light energy, of the action of the electric arc upon noxious odors, to emphasize the need of the energy of light to keep our houses and hospitals pure. Disease will not breed in houses flooded with sunlight and air. The action of the sunlight is to destroy millions of morbific germs daily, not only in the air and on the surface of the soil but also in the water of streams. The latter has been shown by the experiments of Buchner, Praunitz[3] and Procaccini.[4]

The habit of keeping the window shades down, a very common practice even in the absence of direct sun glare on the window, is in direct opposition to fundamental physiological principles. Sunlight is not only purifying to our atmospheric environment, in its destructive action upon micro-organisms, thereby preventing disease, but it has a

[1]Berichte d. d. Chem. Gesellschaft, 1903, Bd. XXXVI., s. 3035.
[2]See Sensitization, Chapter XX.
[3]Influence des égouts de Munich sur l'Isar, Munich, 1889.
[4]Influence de la lumière solaire sur les eaux d'égouts. Annalê de l'Institut d'Igaine sperimentale, t. III., 1893.

still more deep and intimate human relation of a sanitary nature, for an abundance of light energy is a necessary condition of mental and bodily well-being. The recognition of its tonic psychical power is universal; the practical application not always made. In all properly organized peoples there is a love of light, and a fear of darkness is not confined to children. The sense of powerlessness, danger and alarm which the latter induces is shown by adults as well. Light energy is essential for all the purposes of life, for the supply of oxygen upon which existence depends. It is a universal stimulus. When it falls upon the eye there are established functional activities in the brain which are associated with intellectual and emotional states. That the blue frequencies exercise a depressing effect and the red an exciting effect upon the brain seems well established; but in this connection it is neither the one nor the other which is considered but a complex of all the frequencies, heaven's own mixture the white light, that envelops us with its all-pervading energy, which is the normal psychical atmosphere. Variations in its intensity have in all probability widely different constitutional effects. But although the quality and intensity of light energy demanded by the individual living organism may vary, the need for it and dependence upon it is imperative for all.

The influence of solar light as a disinfectant is chiefly upon the surface of translucent or opaque bodies. Any medium which cuts off the chemical frequencies from the blue into the ultra-violet region, as glass, dust and fog, as well as a clouded atmosphere, prevents this disinfectant process, so necessary to perfect hygiene and sanitation. Consecutive days of rain, mist and fog give an opportunity for the growth and development of pathogenic organisms. They usually are followed by epidemics more or less severe of the diseases dependent upon the activity of these germs.

Houses that are closed for several months in the year should be left with the shades all up and curtains looped back, in order that the sunlight may penetrate every nook

and corner. In this way the growth of germs inimical to health will be prevented. And not only when they are closed but when occupied they should be flooded with sunlight. For this reason, heavy curtains which obstruct the ingress of the sun's rays are pernicious in the extreme. They not only exclude the light, but they readily become saturated, so to speak, with germ-laden particles of dust, and it remains only for the occupants of the house to become a little worn, tired, anæmic, from over care and anxiety, or in women from an exhausting menstrual flow, for these germs to find a fit lodging within the tissues and to actively develop.

By the action of those frequencies which penetrate and are absorbed, physically, there is established a synchronous vibration with oxygen molecules, which results in an impartation of energy and an increased oxidative power.

Thus the chemical activities of light serve in hygiene, sanitation, and also in disease: In the one instance to maintain health, in the other to disinfect or destroy pathogenic organisms, and in the latter to check the inroads of disease by increasing not only the red blood supply but the white as well and the functional activity of the entire organism.

CHAPTER VI.

The Action of Light Energy upon the Higher Organisms.

Introduction.—There is in animals as in plants a stimulating influence on the functions of tissue elements and organs by the action of light. The impartation of energy to the living organism is transferred into a stimulus by which all the vital processes are quickened and heightened. There is produced by this stimulus of light either a direct influence upon the irradiated protoplasmic cells, or there is brought about indirectly, through the sense organs and nerves, certain functions on the part of given organs.

The Influence of Light upon the Development of Animals and Man.—The development of many animals is dependent on light and without it development proceeds slowly or is suspended altogether. It was observed by William Edwards[1] that frog spawn in an opaque glass died, while spawn in a transparent glass became duly developed.

Tadpoles develop more slowly in the dark than in the light. Schnetzler's[2] experiments prove that white light is more favorable to such development than green.

The degree of development of animal organisms is influenced differently by the different frequencies of the spectrum.

[1]De l'influence des agents physique sur la vie, Paris, 1824.
[2]Archives des Sc. Physiques et Naturelles, 1874, Vol. LI.

It was observed by E. Yung[1] that violet light helped on the development of the embryo of rana, salmo, and lymema, which was hindered or disturbed by other parts of the spectrum or by darkness.

Beclard[2] observed that flies' eggs develop more quickly under blue and violet glass than under red, yellow, green or white.

Guarinoni[3] from his experiments believes that violet light acts more favorably on silkworms; while Goodnew noticed that maggots are much more quickly developed in pieces of meat exposed to the light than in meat kept in the dark. In his study on the activity of light on polypi Loeb found that the growth is not especially influenced by all the rays, but that only the more refrangible, that is, the blue rays, promote growth. The same effect on the other hand is produced by red in darkness.

Recently Leredde and Pautrier[4] have made a study of the development of animals under the influence of the energy of different parts of the spectrum. As subjects of experiment, tadpoles of the common rana temporaria were used. The solar spectrum divided into two parts was used; the one comprising all the energy from the green, blue, indigo and violet, and the other the energy from the red. Two aquariums were constructed, one of photographer's red glass, colored with proto-oxide of copper, and the other of blue glass colored in cobalt blue. Each was covered with a glass of the same color as the aquarium, leaving just space enough for oxygen renewal. Examined spectroscopically the red glass permitted the passage of all the rays up to the line D, that is to say all the red and the beginning of the orange; for the blue glass the violet, indigo blue and the beginning of the green. The tadpoles subjected to the experiment were caught the same day in the same pond and preserved for

[1]Comp. Rend. Acad. des Sc., Vol. LXXXVII.
[2]Compt. Rend., 1858.
[3]Quoted by J. M. Eder, Ueber die chem. Wirkungen d. farb. Lichtes, Vienna, 1879.
[4]Leredde and Pautrier, Photobiologie et Photothérapie.

some days in a large white bell glass. They presented no differences of tail, size or development. They were divided into three groups, one of which was placed in the red aquarium, another in the blue while the third was put in the white bell glass to serve as a control. Other than the difference in the energy of radiation to which they were exposed all other conditions were exactly the same. The food was the same for all and was provided by the water of the pond, which filled the aquariums and which furnished infusoria, Daphnes and Cyclops. The illumination was always bright, as the aquariums were either placed in the garden of the dermatological establishment or before the laboratory window. The intensity of the light employed ought to be considerable, as it is reduced considerably by filtration through the colored glass. When feeble diffused light is employed, it is equivalent to darkness in the centre of the aquaria, however thin the glass may be.

At the end of a month there was the greatest difference in the tadpoles of the red and blue aquaria. In their book, Leredde and Pautrier present photographic illustrations, showing these differences. In each of the aquaria one died. Of the three survivors in the red aquarium, they were all still in the tadpole state with their caudal membranes. One of them had two pairs of feet feebly developed and breathed by the pulmonary method, but the other two had no rudimentary members, moved themselves simply by their nutatory membrane and breathed by the bronchial method, the bronchi being covered by a cutaneous operculum. On the other hand the three tadpoles raised in the blue-violet light had no longer caudal membranes. They were represented only by a little stump in process of disappearance. Their two pairs of feet were completely formed and they respired well by the pulmonary method. The photographs showed these differences very clearly—on the one side there are true tadpoles almost analogous to fish, on the other true frogs almost completely adult. The experiments of Leredde and Pautrier were also made to show the greater activity in

cellular division, which alone could explain the apparent differences and also to measure this karyokinetic activity. To this end a tadpole of a urodal bactrachian, the Trito Cristatus, was selected. This tadpole presents a caudal membrane which is excellent for the purposes of study. Although it contains a great number of chromatophores it is very little pigmented and so small that if it is carefully cut off and skinned in the direction of its thickness it is an excellent subject for the study of the yellow elements, conjunctival cells, capillaries in formation and epithelial cells in karyokinesis.

Larvæ of the triton were kept for three weeks in blue and in red aquariums. Their caudal membranes were then removed and the preparations colored with hematin-eosin. The preparations were then examined by the movable graduated stage, as in examination of the blood, to establish the leucocytic equilibrium. Section by section was examined, counting 4,154 epidermic cells in the sections from the tritons raised under blue glass. In these they found 52 figures of cellular division or a little over 1/79 of the cells in karyokinesis. Upon examination of the tritons raised in the red aquarium they counted 2,613 cells and 14 in karyokinesis, or about 1/186 of the entire number.

Subsequent to their experiments they found that Jakimovitch[1] had reported similar experiments in a Russian publication with similar results. He also observed that the larvæ of tritons developed better in light than in darkness, and that the karyokinetic activity of tadpoles grown under different lights was sensibly greater under violet energy than under the energy of all the other frequencies. He made his observations upon the bronchi rather than the caudal membrane, however.

The conclusion is, therefore, reached that light exercises an incontestable influence upon the development of the higher organisms, and that in the phenomena of karyokinesis the violet is the most active.

[1]Westnick obchestvenog hygieny, Aug., 1891.

The Influence of Light upon the Movement of Animals.—There is observed among the higher organisms the phenomenon of movement under the influence of light. These movements are analogous, in a higher scale, to the phototactic movements of unicellular growths, studied under the influence of light energy upon the elementary forms of light.

The simplest manifestations of this phenomenon is in the lower forms of animals, where the nervous system is rudimentary.

In this connection the experiments of Gruber, Dubois, Loeb and Finsen are of interest.

Sensibility of the Cutaneous Investment of Animals to the Chemical Rays.—Gruber's[1] experiments were made upon the Lumbricus or ordinary earthworms which have no eyes, and upon some blind salamanders to the end of removing the complications which would arise from the reflex movements due to the action of light on the visual organ. They were found to be sensitive to the presence or absence of light, and also to the different frequencies of the spectrum. They tend to flee from illuminated places and shunned completely the areas exposed to the action of the blue-violet light. These animals seem capable, therefore, of distinguishing between light and darkness, and of recognizing the rays of varying refrangibility. This phenomenon Gruber observed even with decapitated earthworms, and is to be explained by a cutaneous sensibility to the influence of light.

Dubois[2] from similar experiments with proteus has shown that it is most active under the influence of red frequencies, least so under the influence of blue frequencies. He observed this animal flees from blue-violet light to take refuge in the dark.

Finsen[3] has carried out a number of interesting observations as to the irritating properties of the chemical frequencies. He observed that very young salamanders lying at the bottom of a dish of water are not disturbed by red or yellow light, but by blue they were quickly excited to movement; the same is true of the ordinary earthworms, which would collect beneath the red and avoid the blue-glass compartment. These were the same results as were obtained by Gruber and Dubois, and it would appear that various animals can distinguish by their integuments between red and blue, and that while they seem to take delight in the former they avoid the latter. So true did he find this from his investigations and observations that he described a specific photodermatic sense. The same thing is true of common house flies. Finsen also observed that solar light determined movements in the fœtus of the frog and of the salamander. He studied these under the influence of monochromatic light, and found that they were exceedingly numerous under the influence of blue light, and very rare under that of red, yellow or green light. He placed three larvæ of the frog just born in demonstration glasses. Upon exposure to the varying frequencies of light energy he found that most rapid movements were produced under the action of blue light energy, and that the maximum effect was only obtained at the end of a certain time of exposure. This is simply the latent period of induction to every physiologic excitant.

Upon placing some tadpoles raised in red light in solar light, he observed them execute some quick movements, while some tadpoles raised under blue light when so exposed were not excited. He also repeated the experiments of Gruber, placing in an oblong box covered with different colored glasses lumbrici, earwigs, and wood lice. These animals all rapidly grouped themselves under the red glass. This simply illustrates that these animals are naturally photophobic, and accustomed to almost complete darkness in their natural haunts, in the earth or under the rocks.

Finsen in another experiment showed that butterflies who are habituated to bright light preferably grouped themselves in the blue light, presenting at the same time the move-

[1]Versuche über die Helligkeits- und Farbenempfindlichkeit augenloser und geblendeter Thiere. Wiener Sitzungsberichte mathem. natur. Klasse, 1883. Bd. 87.
[2]C. R. Soc. de Biologie, 1890, p. 360.
[3]La Photothérapie, Paris, Naud, 1889.

ment of beating of the wings; while under the influence of red light they remained in repose.

Auerbach[1] authorizes the statement that the action of light energy induces powerful contractions of the protoplasm of frog's spawn. Finsen, in his experiments with frog spawn and salamander germs, noticed that light possessed to a high degree the power of inducing movements of the germ. The blue-indigo and violet frequencies have special power in this way.

With an increasing light energy, daphnia pulex shows increased precision and swiftness of motion.

Harrington and Leaming, quoted by Freund, state that red light is more favorable to the movements of amœbæ, while both the violet and white light have an impeding effect.

The experiments of Parker and Burnett[2] also demonstrate the heliotropic faculty of animals as well as plants. This does not necessarily pertain to animals whose visual organs are intact but is true also of sightless animals. The influence which light exercises upon some animals is of common observation. They are irresistibly compelled by it, it possesses for them a magnetic influence, and they are, therefore, impelled either to turn toward or away from the source of light. In every suburban village in which the streets are lighted with the electric arc there are to be found hundreds of dead insects, moths, etc., about each arc. The attraction is so great that, like the singing of the Lorelei, it impels them to their destruction. Among insects thus blindly attracted by artificial light is the gnat, in whose flame it will singe its wings and lose its life. Wedensky[3] observed that blind frogs will always turn their heads toward the source of light, placing themselves so that its rays may fall symmetrically on both sides of their bodies. Bert[4] observed that when frogs were placed in a box, one-half of

[1]Quoted by Freund, page 412.
[2]American Journal of Physiology, IV., 8, p. 273.
[3]Bull. de l'Acad. des Sc. à Petersburg, 1879.
[4]Revue Scientif., 1878, 42.

which was illuminated and the other half dark, that they would always try to get to the bright part.

With animals, as with plants, there are those which instinctively seek shady and dark places, seeming to have an instinctive dread of light.

It has been shown that animals are influenced by the different frequencies of the spectrum, that is, they have a color sense. Finsen showed that earwigs, wood-lice and earthworms are very sensitive to the short waved frequencies—blue violet—while Gruber, whose experiments have been quoted, showed the same for the earthworm, even blind ones like the triton, being extremely sensitive to this part of the spectrum, seeking refuge either in darkness or in the long and slow waved frequencies of the red, as opportunity offered. The preference for blue violet by butterflies was experimentally shown by Finsen, and is a matter of common observation to the student of nature.

It has been, therefore, very completely demonstrated that the shorter and higher frequencies are much more strongly phototaxic than the longer and slower. The latter, if not present to too great a degree of intensity, produce the same effect as darkness. The phenomena are not always uncomplicated. They are influenced by the supply of oxygen. In the presence of sufficient oxygen the stimulus of light energy is ineffective in Paramœcium bursaria and the obverse when the supply is insufficient. Temperature also influences the phenomena. For example, phototaxic phenomena only appear in some instances if the temperature is raised at the same time. The phenomena are dependent upon the intensity of light, many animals reacting only to changes or to fluctuations in its intensity.

Jacques Loeb[1] in a series of very carefully-conducted experiments on nearly 100 varieties of animals, including caterpillars, butterflies, plant lice, ants, fly larvæ, the larvæ of beetles, various hybrids, etc., demonstrated a

[1]Der Heliotropismus der Thiere und seine Uebereinstimmung mit dem Heliotropismus der Pflanzen, Würzburg, 1890.

heliotropic action on the part of animals which agrees with and conforms to that observed by Sachs for plants.

The following phenomena were exhibited in Loeb's experiments when certain animals were exposed to white light or to blue and violet light from a single light source: (1) They arranged themselves with their long axis parallel with the rays of light; that is so that the rays fell at equal angles on symmetrical areas of the body. (2) The animals if positively heliotropic moved in the direction of the rays until as near as possible to the source of light, and remained there as long as the light did not fall below a minimum intensity, even though in so doing they followed from a lighter to a darker place. Negatively heliotropic animals obeyed the same law, but moved as far as possible from the source of light.

All factors entering into the experiments, temperature, oxygen supply, geotropism and contact irritability, which might influence the movements of the animals, were carefully controlled by Loeb in his work.

His experiments covered headless animals and those having no associating cerebral organs, and he succeeded in making certain animals positively or negatively heliotropic at will. In this way he demonstrated that the movements were not due to a subjective sense or intuition, but to direct stimulation of the muscles by the more refrangible or the blue and violet frequencies. The stimulation was the greater, the more nearly the angle at which the light struck the surface approached a right angle; hence, orientation of the animal in the direction of the light took place before the movement to or from the source of the light.

These experiments conclusively point to a directly stimulating effect upon animal cells by the visible chemical frequencies of light, i.e., the blue and violet. There can be no question but that the stimulation results from a chemical change. By the impingement of these frequencies upon the skin, penetrating as they do to considerable depth, they are no doubt absorbed by the blood.

Chemical Rays Promoters of Energy.—In conclusion Finsen says that "all this demonstrates the biological importance of the chemical rays, which are veritable promoters of life and energy."

Raphael Dubois[1] has shown that in the case of Proteus Anguineus, which lives in the grotto of Adelsberg, the entire skin possesses the property of being excited by the luminous rays.

The Action of Light Energy in the Stimulation of Unstriped Muscular Fibre.—This has been the subject of research and experiment and it was shown by Arnold[2] and Steinach[3] that the incidence of light without heat causes contraction of the pupils in the excised eyes of amphibians and fishes. The sphincter of the iris, which narrows the pupil by its contraction, is composed of smooth muscular fibers containing a brown pigment. Even the iris of the eel when cut out and placed in normal saline solution contracts to light, the green and blue frequencies being the most active. This action is independent of the central nerve system and takes place even though the retina has been removed. The evidence points conclusively to a direct action upon the smooth muscular fiber, i.e., upon the cellular elements. The importance of light as an excitant to the nervous system is not minimized by ascribing a place to the direct action of this agent upon cellular elements.

Other investigators in this field are Brown-Sequard, Heinrich Müller,[4] Reinhardt and Budge.

The phenomenon is regarded by Brown-Sequard as direct muscle irritation by light. For a period of 30 hours after death Harless[5] observed upon human corpses

[1]Sur la perception des radiations lumineuses par la peau, chez les Protées aveugles des grottes de la Carniole. C. R. Acad. des Sc., t. CX., 1890, p. 160.
[2]Landois and Stirling.
[3]Untersuchungen zur vergleichenden Physiologie der Iris, in Pflüger's Archives, Vol. LII., 1892.
[4]Landois and Stirling.
[5]Abhdlgn. d. bayr. Akad., 1848, v. p. 490. Quoted by Freund.

distinct contraction of the pupil of the eye upon exposure to light as compared with that of the closed eye.

Action of Light upon the Skin of Animals—Pigmentation.—Under this head a series of phenomena is to be observed which should be interpreted as phenomena of defence against the action of light, especially against that part of the spectrum of such intense chemical activity. In this part of the spectrum is to be found a source of possible danger to the living organism.

Rôle of Light in the Production of Pigment.—It is of common occurrence that animals whose skins present a diversity of coloring the darkest part is always the dorsal surface of the animal, or the part most exposed to light. In the horse, for example, the abdomen is often white while the back is brown, bay or black. In the case of flat fish but one surface is colored, and that which is exposed to light. Cunningham[1] proved by his experiments that light was the cause of this pigmentation. The well-known fact that many polar animals have a white robe in winter and colored in summer, referred to in this connection by Finsen, is another manifestation of the same phenomenon.

As showing this relation, the experiments of Packard[2] upon fauna of the caverns of America and those of Viré[3] upon the subterranean fauna of France, may be cited. Viré's studies were made upon the Gammarus puteanus, which in the light has an intense gray-green coloration. These cavernical species when placed in catacombs or subterranean passages were partially decolorized in the eleventh month and completely depigmented in the twentieth month by the fusion in all parts of the white points which first appeared in a diffuse manner upon the bodies of the animals.

The inverse action or regeneration of the pigment was obtained by Viré's experiments upon the niphargus puteanus which naturally is white. Upon transportation to the light, these animals toward the second month presented a blackish-green mottling of the integument, soon deepening in confluent spots, resulting in uniformly coloring the animal a greenish brown.

[1]Quoted by Leredde and Pautrier.

[2]Ibid.

[3]Thèse, Paris, 1900, and C. R. du XIII., Congrès Internat. de Paris, d'Anatomie Comparée, p. 3.

Böhn[1] in a study of the evolution of pigment concluded that "in many cases the molecular constitution of pigment can be changed directly by the luminous waves of different lengths." "Until now, a purely alimentary origin had been attributed to the substances which color so variously the pigment of the caterpillar."[2]

Protective Rôle of Pigment against Light.—Of this action the chameleon is a noticeable example. The Vienna physiologist Brücke,[3] 50 years since demonstrated the color scale through which the chameleon would pass on changing from light to darkness.

The chameleon has in the depths of its integument large pigmented cells, or chromatophores, which are particularly mobile. In the dark these rest in the depths. Under the influence of light, the color changes from a gray to almost a black, illustrating their ability to migrate from the depths to the surface and again to the depths.

Brücke showed that the movement of the chromatophores is dependent upon the central nervous system. Darkness acts on the skin of the chameleon as a stimulant, while daylight, even sunshine, reduces the pigment cells to a passive state. When the chameleon is brought into the sunlight it becomes dark by projecting the elongations of the pigment cells to the surface of the body. When they are taken into the dark the animal becomes pale in color because of the drawing back of the dark elongations of its pigment cells, so that they are covered by the light-colored pigment in the upper layers of the cuticle.

[1]L'Evolution du pigment, Paris, Naud, 1901.

[2]Leredde and Pautrier.

[3]Untersuchungen über den Farbenwechsel des Chameleons. Bericht der mathemat. Naturwissenschaftl. Klasse D. K. Akad. der Wissenschaft. Wien, 1852, IV.

Paul Bert[1] carried the experiment still further and exposed one-half the chameleon's body to the red and the other to the blue frequencies; under the former the skin remained light, under the latter it changed to dark. This subject was also studied by Krukemberg.[2]

From the varying behavior of chromatophores under irritation, as strychnine poisoning, rubbing with turpentine, strokes of a magnetic electro-motor and when paralyzed by cutting through the nerves, it is clear that the condition in which the cells extend their processes is the passive condition of rest, and the condition in which they draw in the processes is the active one of irritability.[3] This action of light upon the skin is local. This was demonstrated by Brücke, who placed a band of tinfoil around a chameleon and then placed the creature in the sun. There was as a result a light-colored strip under the tinfoil, while the rest of the body was dark. He further proved that this action was due to light—not heat.

It has been proven with other animals as well as the chameleon that this protoplasmic movement of the chromatophores under the influence of light takes place through the central nervous system.

The experiments of Ehrmann who observed in frogs the direct passage of nerve filaments into the pigment cells, made it probable that the chromatophores are connected with the central nerve organ. Pouchit[4] demonstrated that fishes, turbots for example, changed color under the influence of light. Turbots in whom the sympathetic nerve had been severed became dark in that part of the body in which the nerves had their origin behind the incision. Blinded fishes became dark in color through the spreading out of the pigment cells.

It is surmised by Brücke that there is a reflex action starting from the visual nerve, and that a stimulus of the optic nerve passes on to the central organ, a stimulus which causes the chromatophores to contract; so that when the stimulus is wanting they permanently cover a larger space.

[1]Influence de la lumière sur les êtres vivants. Rev. sc. 1878, 42.
[2]Quoted by Leredde and Pautrier.
[3]Freund.
[4]Acad. des Sc. 1871.

The color of frogs and the sheaf fish is also dependent upon light according to Wittich[1] and E. Du Bois Reymond.[2] These animals were black in the dark and became light colored again under the influence of light. Exner drew attention to the movements of pigment in the eyes of insects as a result of light.

The behavior of these animal organisms with regard to light is perfectly intelligible when it is considered that pigment is a natural protection against light. This is clearly shown in the study of the action of light upon the skin. The following hypothesis as advanced by Finsen as to the phenomena of the skin against light energy, seems rational to the author, viz., that the pigment formed absorbs the light rays, utilizing their energy in transforming them into favorable chemical actions. This will be considered more at length in the study of pigmentation of the skin.

Action of Light upon the Vital Activity of Animals.—Under this group of phenomena is the action of light upon respiration, upon assimilation measured by loss of weight, and differences presented by animals raised in the light and in darkness from the point of view of alimentation, weight and blood.

Changes of Form in the Contractile Pigment Cells.—It is a well-known fact that changes of light cause changes of form in the contractile pigment cells of many fishes, amphibia and reptiles. In this way there are produced changes of color in the animal. For example, the black pigmented cell of the frog's skin, which in the dark have widespreading ramifications, under the influence of a bright light, grad-

[1]Mueller's Archives, 1854.
[2]Untersuch. zur Naturlehre des Menschen u. der Thiere, von Moleschott I. 1858, Bd. V.

ually contract into little balls, making the skin appear much lighter in color.

Influence of Light upon the Respiratory Chemism.—From the observation upon this function in relation to light it was concluded by early observers that light appears to augment the activity of the respiratory chemism, and that the power so to act belongs to the chemical end of the spectrum.

Differences of Weight Presented by Animals in Light and Darkness.—This was studied by Bidder and Schmidt,[1] who, in their experiments upon a young cat, observed that the loss of weight was greater in the light than in darkness. Fubini[2] arrived at the same conclusion.

Yung[3] in his investigations made upon tadpoles deprived of nourishment, observed that they died more rapidly under the influence of the chemical part of the spectrum than under that of any other light. From these experiments it appeared that the blue and violet light energy caused a more rapid consumption of the reserve material.

Influence of Light upon Assimilation and Disassimilation.—Borissoff's experiments contradicted those of the observers which have just been quoted.

They were made upon four young dogs of the same weight, same color, and for whom all the conditions of nourishment and aëration were equal. Two of the dogs were placed in obscurity and two in light.

The dogs kept in the light ate more than the others, and after having a less weight during the first week than that of dogs kept in the dark, they weighed at the end of a month 220 grammes more than the latter. The same experiment repeated with rabbits gave the same result. Light then acts

[1]Verdauungssäfte und der Stoffwechsel. Leipzig, 1852, 317.
[2]Ueber den Einfluss der Lichtes auf das Körpergewicht der Thiere. Untersuchungen zur Naturlehre von Moleschott, 1876. Bd. XI. 5, 488.
[3]C. R. Acad. des. Sc. t. LXXXVII. et Arch. de Zool. expér., 1878, t. VII., 2.

as an excitant for the organism. Borissoff[1] admits that the changes under the influence of this stimulus are more actively effected, i.e., tissue change goes on more rapidly, but that at the same time the nutritive materials are accumulated and fixed with more facility.

Action upon the Blood.—According to Borissoff, who examined the blood of these animals, there was no influence upon the formation or the number of the red blood cells or of the leucocytes, nor upon the rate of hæmoglobin.

The Action of Light Energy upon Blood Cells.—Uskoff[2] also made a study of the protoplasm of blood cells. The white corpuscles of frogs' blood showed more and longer processes in red light than in violet. Under the influence of the red frequencies they were more spread out for the most part in the form of hardly visible discs.

On the other hand Hermann[3] is authority for the statement that leucocytes are not sensitive to light while red corpuscles show distinct changes of shape.

It was observed by Finsen[4] that the red corpuscles in the blood of tadpoles changed shape under the influence of sunlight; they contracted and became rounder.

Hammer[5] is authority for the statement that there is no direct action of light upon the blood corpuscles, but that the effect is due to the establishment of a motion in certain nervous elements of the skin in connection with pigment cells by the action of the ultra-violet frequencies, and that secondarily this motion leads to hyperæmia, inflammation and pigmentation. His experiments are of the greatest interest, and to the author's mind only tend to prove that the action of light is primarily upon the blood itself. They were made on tadpoles, salamander eggs, earthworms, etc., for the purpose of studying not only the action of light but

[1]Quoted in Romme. Principles of Photothérapie, Presse Médicale, Sept. 21, 1901.
[2]Centralblatt f. d. Med. Wissensch. 1879 No. 25.
[3]Quoted by Strebel, p. 6, and by Freund, p. 412.
[4]Ueber die Bedeutung d. chem. Strahlen, Leipzig, 1879.
[5]Auerbach: Centralblatt für die Wissenschaft, XIX., p. 1.

the relationship between the motility of cells and monochromatic light, and demonstrated that light provoked movements in the fœtus, and that this action must be attributed to the violet frequencies.

This effect on fœtal life seems but additional proof of the action of these frequencies upon the blood, for no more intimate relationship exists between the parent and fœtus than through the medium of the placental circulation. It is only necessary to recall how quickly the red blood corpuscle is stimulated to increased function by the action of light energy to appreciate that it is not necessary to explain its effect on fœtal life by the action upon the peripheral nerve endings.

If the action is primarily upon the nervous elements of the skin, the same effect should be obtained in lupus vulgaris and syphilitic lesions, for example, by simply directing the light energies upon the part, without compression. To secure results in these and similar conditions, however, compression is necessary, thereby securing the dehæmatization requisite for a direct action upon the tissues. In both the pathologies mentioned, the crying need is for blood rich in oxygenating power; in the one to combat the micro-organisms primarily, and in the other to actively increase oxidation.

The Action of Light Energy upon the Eye.—It is not only in the skin, however, that important changes are established by the action of light energy, but in the eye as well. Since the advent of electric lighting, there have been noted by different observers a variety of effects from a simple conjunctival irritation with tired eyes to very severe ocular disturbances. According to Ogneff,[1] from the prolonged action of light energy of great intensity, in which the violet and ultra-violet frequencies preponderate, there is produced a necrosis in the cells of the cornea in the case of rabbits, pigeons and frogs. This necrosis of the cells of the cornea

[1]Untersuch. d. physiol. Institut, Heidelb., Vol. I., u. ff. Quoted by Freund.

is produced by amitotic nuclear changes; from a brief exposure mitosis only results. He found the other parts of the eye, the lens and the vitreous humor, were not at all affected, the retina only slightly. This experimenter was of the opinion that he guarded against any action of the thermal frequencies in his experiments.

The red coloring matter, or visual purple, "rhodopsin" which was proved by Boll[1] to be present in the outermost portion of the rods during life is bleached by the action of light upon the retina. This bleaching takes place during daylight, but the coloring returns when the eye is placed in darkness. Kühne[2] showed that by illuminating the retina, actual pictures, as, for example, the image of a window, could be produced on the retina of either living or dead frogs and rabbits, as by a photographic process, but they gradually disappeared.

By the use of a 4% solution of alum Ewald and Kühne fixed a sharp picture or optogram in a rabbit's eye dilated with atropin, at a distance of 24 cm. from the eyes.

Visual purple, or rhodopsin, withstands the action of all oxidizing reagents; zinc chlorid, acetic acid, and corrosive sublimate change it into a yellow substance, but it becomes white only through the action of light. The obscure or dark thermal frequencies are without effect, while it is decomposed above a temperature of 52°C. It is doubtful just how far this action of light on the visual purple affects the power of sight.

Vision cannot be explained by the formation of optograms by the visual purple, for it is absent from the cones, and the cones are only present in the fovea centralis.

It is the rods and cones which are endowed with what Johannes Müller terms specific energy, that is, they alone are set into activity by the swing of the oscillating corpuscles of light energy in such a way as to produce those impulses

[1]Landois and Stirling, Text-book of Human Physiology, 4th edition, p. 942.

[2]Landois and Stirling, 4th edition, pp. 980-981.

which result in vision. Light allowed to act upon the retina for a long time, and especially if it be intense, causes fatigue of the retina, which begins sooner in the centre than in the periphery of the organ. This retinal fatigue comes on rapidly at first, but develops more slowly subsequently.

It has been demonstrated by Kühne[1] that the nature and the amount of light influenced the condition of the hair-like processes sent down between the rods and cones, and also influenced the formation of pigment granules of the pigmentary cells of the retina.

In a frog kept for several hours in the darkness the protoplasm of these pigment cells is retracted, and the pigment granules lie chiefly in the body of the cell and in the process near the cell. In a frog kept in bright daylight, the processes loaded with pigment penetrate downwards between the rods and cones as far as the external limiting membrane. A retina that has been kept in the dark changes its electrical conditions when light suddenly falls upon it; the electrical current which passes normally from the retina to the brain is made stronger.

The maximum of stimulation for the eye accustomed to darkness is found in yellowish-green close to the thallium line. On the other hand the eye adapted to the light reacts most to the yellow D-line of the spectrum.

It was proved by Engelmann that frogs from whose eyes light was artificially excluded reacted with contraction of the interior cones of the retina upon exposure of the skin of the back to light energy. In this fact is to be found the proof that the stimulus of the light energy reaches the brain by a centripetal course, and is able thence to induce motor phenomena.

When the brain is removed, it has been shown by Buedingen that this reflex action does not take place. From this the conclusion must be reached that this transformation of the light energy stimulus takes place within the brain itself.

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[1]Landois and Stirling.

Stimulus of the visual areas may produce spectra. This phenomenon cannot be produced at will by all persons. Cardanus (1550), Goethe, Nicolai, and Johannes Müller could produce spectra at will.[1]

It has been shown by von Helmholtz,[2] Bence Jones,[3] Dupré and John Tyndall that the lens possesses the power of fluorescence to a high degree.

Von Helmholtz, after cutting out all the spectrum, including the violet rays, succeeded in seeing the ultra-violet rays, which had a feeble grayish blue color. The heat rays in the colored part of the spectrum are transmitted by the media of the eye in the same way as through water. The existence of the ultra-violet frequencies is best ascertained by the phenomenon of fluorescence. As the media of the eye themselves exhibit fluorescence (von Helmholtz), they must increase the power of the retina to distinguish these rays. According to Brücke, ultra-violet frequencies are not largely absorbed by the eye.

Tyndall found upon bringing his eye into a violet ray that he noticed a bluish white glimmer filling the space in front of him. This glimmer comes from the fluorescent light in the eye itself. The crystalline hue of the eye when looked at from without lights up brightly at the same time." It seems very probable that this peculiarity of the lens common also to the vitreous body is the explanation of the ability on the part of some persons to perceive sensations of light under the influence of Roentgen and Becquerel rays. It is not impossible, as suggested by Freund, that electric stimuli of the retina and the optic nerve may have something to do with it.

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[1]Landois and Stirling, Text-book on Human Physiology.
[2]Ibid.
[3]Medical Times and Gazette, London, Aug., 1866, pp. 163-167.